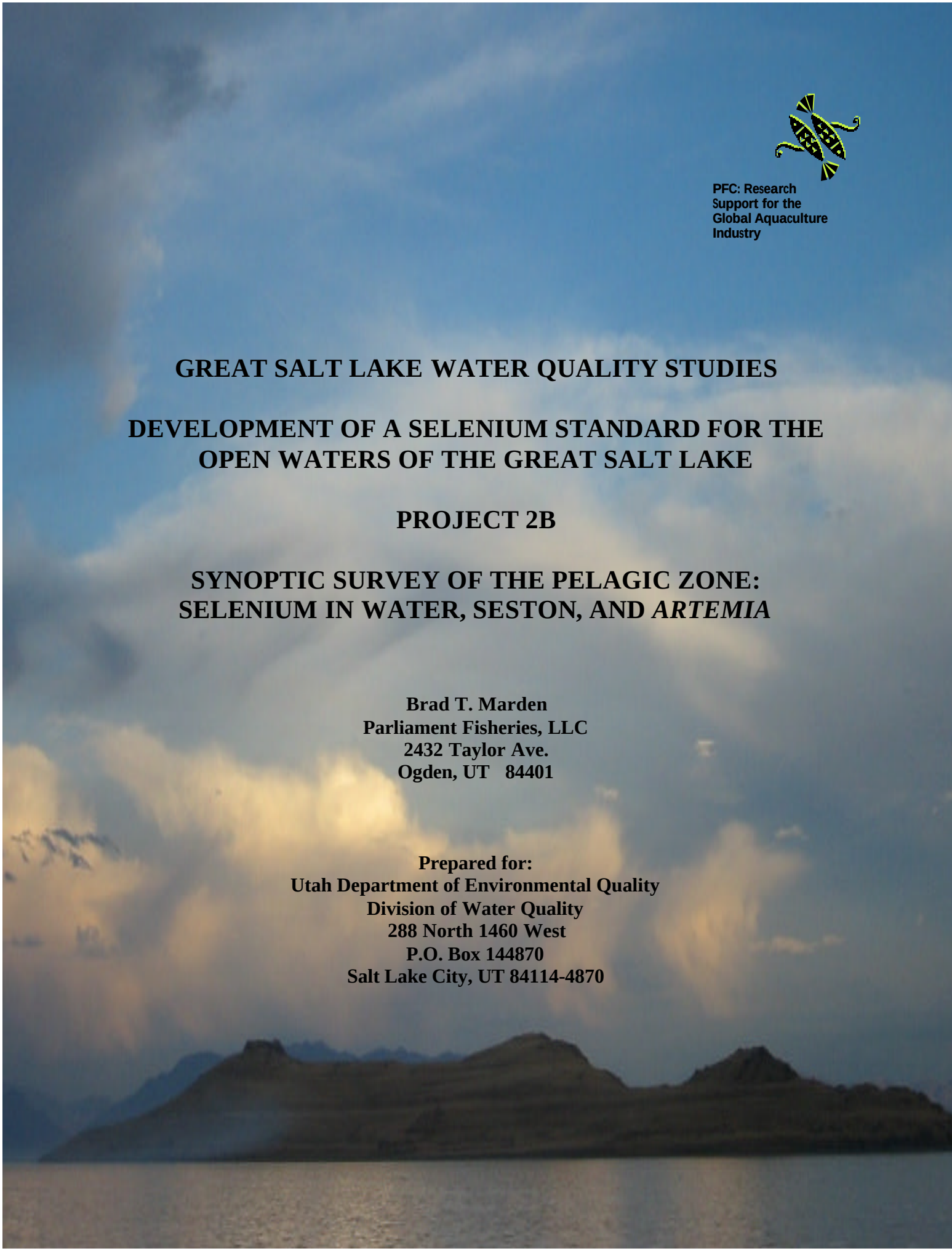


PFC: Research Support for the Global Aquaculture Industry

GREAT SALT LAKE WATER QUALITY STUDIES

DEVELOPMENT OF A SELENIUM STANDARD FOR THE OPEN WATERS OF THE GREAT SALT LAKE

PROJECT 2B

SYNOPTIC SURVEY OF THE PELAGIC ZONE: SELENIUM IN WATER, SESTON, AND *ARTEMIA*

Brad T. Marden
Parliament Fisheries, LLC
2432 Taylor Ave.
Ogden, UT 84401

Prepared for:
Utah Department of Environmental Quality
Division of Water Quality
288 North 1460 West
P.O. Box 144870
Salt Lake City, UT 84114-4870

EXECUTIVE SUMMARY

A field study of the pelagic zone of the Great Salt Lake, Utah (GSL) was conducted from April 2006 through August 2007 to document selenium concentrations in GSL water, seston, and the dominant zooplankton—brine shrimp (*Artemia franciscana*). The transfer of selenium through trophic levels (i.e., water phase to seston, and then to brine shrimp) in the pelagic zone of the GSL was assessed. Population dynamics of brine shrimp and phytoplankton were also documented. Limnological conditions of the GSL were recorded with respect to those factors that play a key role in the growth and survival of zooplankton and phytoplankton.

The brine shrimp displayed characteristic cyclical patterns of population growth and decline throughout the summer months. Both modes of reproduction (e.g., ovoviviparous and oviparous) were documented from May until December, although oviparous reproduction dominated after September. The terminal population collapse occurred in late December when the water temperature dropped to less than 5 degrees Centigrade. The population structure and size was unremarkable with respect to earlier research on the GSL. Population parameters were well within the boundaries of previously reported population cycles on the GSL (Stephens, 1997, 1998, 1999; Belovsky and Larson, 2001). Mature adult abundance (1.21 adults/L & 0.68 adults/L), average productivity per location (6.97 cysts/L & 3.45 cysts/L), fecundity (89 cysts/brood & 74 cysts/brood), biomass (0.69 mg/L dw & 1.05 mg/L dw), cysts in the water column (21.63 cysts/L & 33.95 cysts/L) , and commercial harvest yield (16.6 million pounds & 14.9 million

pounds) for 2006 and 2007 respectively, indicate that this population is in a generally healthy condition (Appendices 2, 3, 4, & 5). As such, *Artemia* biomass, whether in the form of overwintering cysts or live brine shrimp, was prevalent throughout the year for foraging birds.

The phytoplankton population was initially composed of diverse taxa; in May 2006 there was a mixed population primarily consisting of green algae (Chlorophyceae), diatoms (Bacillariophyceae), blue-green algae (Cyanophyceae), and small numbers of dinoflagellates (Dinophyceae). Later in the summer the population was more homogenous. Chlorophytes progressively increased in relative dominance from 59% in May to 97% in August, 2006. *Dunaliella* was the most dominant genus represented in the GSL over the summer of 2006.

Chlorophyll-a measurements from water column samples showed declining values at the beginning of spring (7.0 ug Se/L in April to 3.2 ug Se/L in late May 2006) (Appendix 7.1). The concentration of chlorophyll-a over the 2006 summer was between 1.3 and 16.0 ug Se/L. Chlorophyll-a increased steadily, as the brine shrimp population declined in October 2006, from single digits to 20.8 ug Se/L. The highest chlorophyll-a concentration was measured in January 2007 (41.7 ug Se/L). Average chlorophyll-a in 2007 was 12.1 ug/L. From May 2007 to August 2007 the chlorophyll-a concentration was between 1.5 and 8.5 ug/L.

Total selenium concentration results for water were quite consistent spatially but not temporally. The geometric mean of selenium in water for all sample dates and locations was 0.61 ug Se/L (Appendix 8.5). The lowest and highest concentrations of selenium in water were 0.39 and 0.90 ug Se/L, respectively. 2007 had the most consistent results for selenium in water samples. From January 2007 to August 2007 there was a net increase of 0.11 ug Se/L is dissolved selenium. The average net change in total selenium for each sampling date was +0.026 ug Se/L.

Among seston selenium concentrations, the geometric mean was 1.32 ug Se/g and the arithmetic mean was 1.43 ug Se/g in 2006, and in 2007 the geometric mean was 0.86 ug Se/g and the arithmetic mean was 1.08 u Se/g (Appendix 8.3). The particulate fraction of selenium in water was determined from the seston selenium concentration reported on a per-liter basis (i.e., the number of liters filtered for each seston sample). The geometric mean of selenium in seston using a per-liter basis was 0.10 ug Se/L and the arithmetic mean was 0.11 ug Se/L for 2006. The 2007 geometric mean for seston in water was 0.13 ug Se/L and the arithmetic mean was 0.14 ug Se/L (Appendix 8.4). The arithmetic mean concentration of selenium in adult *Artemia* tissue in 2007 was 4.32 ug Se/g and the geometric mean was 4.30 ug Se/g (Appendix 8.1). The nauplii/cysts fraction in 2007 showed a geometric mean value of 2.32 ug Se/g and an arithmetic mean value of 2.42 ug Se/g. The nauplii were a factor of 0.538 multiplied by the adult selenium tissue concentration. Average values for selenium in brine shrimp tissue were below the 5 ug Se/g level of concern for protection of most birds.

No significant differences in selenium concentration among water samples were found for location ($P = 0.437$, df: 2, 103) or water depth categories ($P = 0.099$, df: 2, 103). Results for water samples did show significant differences in selenium concentration across sample dates ($P < 0.01$, df: 16, 89). 2007 results for selenium in brine shrimp tissue were significant for location ($P = 0.026$, df: 2, 42). They were also significantly different for depth categories ($P = 0.050$, df: 1, 43). There were statistically definable differences temporally in brine shrimp tissue selenium concentration ($P < 0.01$, df: 7, 37). Seston samples were uniform for site depth ($P = 0.794$, df: 2, 99) and geographic location ($P = 0.211$; df: 2, 99), yet differed substantially across sample dates ($P < 0.01$, df: 16, 99).

The data suggest that there are temporal events that influence selenium loading into specific trophic compartments. However, when results for each biological or physical compartment are examined collectively over the course of multiple months, and evaluated spatially, they do not differ in statistical measures of central tendency. Although some putative factors that may affect the temporal pattern of selenium in biological tissues have been inferred (e.g., interaction between *Artemia* and phytoplankton population fluctuations) it is not clear from the present study which factors are most important, or mechanistically, how such factors, or biochemical processes, may function within the GSL biota.

The selenium load in brine shrimp biomass is an inconsequential factor in the overall mass balance of selenium in the GSL; the maximal load for 2007 in *Artemia* biomass was 87.0 kg and the average load was 45.1 kg. The estimated amount of selenium removed

from the GSL via commercial harvesting of brine shrimp cysts is similarly trivial—2.21 kg to 10.75 kg per year. In 2006 the industry removed 4.2 kg and in 2007 3.74 kg of selenium.

There is little evidence of biomagnification in the selenium results—as has been corroborated in the scientific literature and by other authors in the GSL Selenium Study Group (Wurtsbaugh, 2007).

The most essential outcome of this study was to provide resource managers with quantitative information on the trophic transfer of selenium from water to seston and then to brine shrimp tissue. In this study the 2006 brine shrimp results were determined to be biased below actual values. Some procedural improvements were made and the resulting data collected from 2007 were quite reliable. Analyzing the 2007 data using least squares regression provided a tropic transfer factor for selenium from seston to brine shrimp of 2.57. The partition coefficient (Kd) for dissolved selenium in water to seston (dry weight) is 1841. The overall bioconcentration factor for total selenium in unfiltered water to adult brine shrimp tissue is 6494, and for dissolved selenium in filtered water to brine shrimp tissue the BCF is 7634. Laboratory studies on the progression of selenium through each trophic level in an artificial food web are currently underway (Grosell, 2007). The data derived from such controlled studies can be used in conjunction with field-generated transfer factors to more effectively model the trophic transfer of selenium through the GSL food web.

INTRODUCTION

The study was undertaken to support the State of Utah Department of Environmental Quality, Division of Water Quality in their effort to establish a site-specific water quality standard for selenium in the Great Salt Lake. This process involves an in-depth, multi-disciplinary approach for evaluating and modeling the transfer of selenium through identifiable trophic compartments of the GSL food web. The goal of this and related studies is to understand the transport, loading, loss, biogeochemical cycling, bioavailability, fate, and impact of selenium on biota within the GSL ecosystem. This information will be used to model changes that may occur as a result of increased selenium loading into the waters of the GSL. One of the simple, but very challenging, questions we are trying to address is: What impacts can be expected in the critical biota (i.e., brine shrimp, brine flies, and avifauna) found within the GSL, and its surrounding environs, if the selenium load into the GSL were increased? This is one of many questions being addressed by the GSL selenium study group, but it is the preeminent question that forms the conceptual basis for this current study on selenium in water, seston and brine shrimp (*Artemia franciscana*) in the pelagic zone of the GSL.

This preliminary report provides a summary of a detailed investigation into the trophic transfer of selenium from the water phase to seston (suspended particulate fraction) and then to brine shrimp. Also included is an in-depth examination of the population dynamics of brine shrimp and the phytoplankton population that comprises the dietary foundation for the brine shrimp. Brine shrimp population dynamics are considered from three perspectives: 1) comparative population dynamics as a measure of population

integrity, 2) reproductive capacity, cyst production, and biomass for foraging birds, and 3) as a biological conduit through which selenium is modified and transferred to higher trophic level consumers. Phytoplankton population dynamics were studied somewhat less rigorously, but are evaluated in sufficient detail to ascertain the dominant algal taxa and general spatial and temporal patterns. Limnological conditions are examined with respect to key abiotic factors that exert a pronounced influence on the GSL biota.

Selenium in each trophic compartment was evaluated, and transfer factors are described. The data are ultimately intended to be incorporated into the framework of the conceptual model of selenium in the GSL as developed by Johnson (2006) and further refined by CH2M HILL.

It should also be acknowledged that the data presented herein are from a rather extensive field investigation. Inherent in any large-scale field study there is an unavoidable element of surprise, such as irksome delays, equipment malfunctions, unanticipated logistical obstacles, weather-related complications, and other challenges. During this field study there was a need for periodic refinements, improvements, and modifications in the sampling and analytical procedures. In particular, improvements were made in the sample preparation of brine shrimp tissue that remedied problems in the 2006 samples. The outcome of this process is, hopefully, a better understanding of the GSL ecosystem as well as the development of improved experimental methods that can help the DEQ/DWQ during future scientific inquiries into the fate and effects of contaminants within the GSL ecosystem.

METHODS

Geographic Regions of the Great Salt Lake

This study was conducted exclusively in the South Arm (Gilbert Bay and Carrington Bay) of the Great Salt Lake. Any reference to the Great Salt Lake (GSL) hereafter refers only to the South Arm and excludes the region of the GSL north of the railroad causeway, unless otherwise specified. For the purposes of this study three regions of the GSL were defined, and clusters of sample sites were located in each region (Figure 1). The regions were based on primary sources of inflow. Ogden Bay and the northeast region of GSL receive water from Farmington Bay and Ogden, Weber, and Bear River drainage basins. In the southeast region of the GSL, drainages from Tooele Valley, the Oquirrh Mountains, and overflow canals from the Jordan River provide the predominant inflow volume into the lake. This region of the GSL is also nearest to the drainage zone for Kennecott's outflow. The central region of GSL (north of Hat Island) is isolated from any specific surface inflow source and is primarily a mixing zone of currents from Gilbert and Carrington bays. Deep brines from Gunnison Bay (North Arm) of the GSL are channeled along a subsurface fault ridge (Allen Ridge) in this area of the lake. Due to the known differences in lake current characteristics and tributary influences among these three regions, site selection was stratified to include representative sample sites from each of these areas.

Sample Site Locations and Characteristics.

Within each region, further stratification of sample site designation was based on depth and substrate (Table 1). Previous studies suggested that depth and substrate may have an influence on phytoplankton and *Artemia* population growth and abundance (Marden, unpublished). Deep sites of the GSL with an associated deep brine layer may be subjected to profoundly different geochemical cycling mechanisms than those associated with shallow or medium-depth sites (Naftz, pers. com.). Light penetration and temperature factors also differ markedly between these sites and likely play an important role in biogeochemical dynamics. Depth categories included shallow (1-3 meters in depth), medium (5-6 meters in depth), and deep sites (7-8 meters in depth). The respective elevation contours were roughly 4190-, 4180-, and 4170-foot contours.

The substrate differed among the depth categories. Shallow site substrate is predominantly characterized by the presence of calcified biostromes and oolitic sand. Biostromes, also referred to as bioherms or stromatolites, are calciferous formations that markedly increase the substrate surface area and may provide a unique micro-habitat that supports microalgae and benthic invertebrates (Wurtsbaugh, 2007). Medium-depth site substrate is generally mixed sands and mud. The deep site substrate is a gelatinous mud (described as "ooze" by Johnson, 2007) composed of decomposing organic matter intermixed with inorganic components. The substrate at each deep site is below the chemocline, or deep brine layer, which is formed by a dense North Arm brine layer (with a salinity typically in the range of 170 to 200 parts per thousand [ppt]) and characterized

by an anoxic and strongly reducing hydrochemical profile (Naftz, 2007). Sample site locations, depth characteristics, and substrate composition are detailed in Table 1.

Table 1. Sample site characteristics and geographic coordinates.

SITE ID	Max. Depth	Depth Category	Region	Substrate	Latitude	Longitude
1	2	Shallow	Northeast	Stromatolite/Mud	41.07.767	112.17.631
2	6.5	Medium	Northeast	Sand/Mud	41.05.097	112.21.145
3	8.5	Deep	Northeast	Gelatinous Mud	41.05.207	112.24.372
4	2	Shallow	Central	Stromatolite	41.05.137	112.35.437
5	6	Medium	Central	Sand/Mud	41.07.066	112.33.514
6	9	Deep	Central	Gelatinous Mud	41.06.440	112.38.260
7	1.5	Shallow	Southeast	Stromatolite	40.52.685	112.13.838
8	6	Medium	Southeast	Sand/Mud	40.49.524	112.11.431
9	8.5	Deep	Southeast	Gelatinous Mud	40.50.786	112.16.711

Sample site locations are portrayed in Figure 1. It is evident from the map that sample sites were clustered regionally. Bathymetric contours, along with field validation of substrate characteristics, were used to define site location according to depth category designations. A strictly randomized approach for sample site designation, along with a greater number of sample locations, was simply not feasible given the scope and financial resources for this project. A stratified-random approach was determined to be a manageable and sound approach for the experimental design.

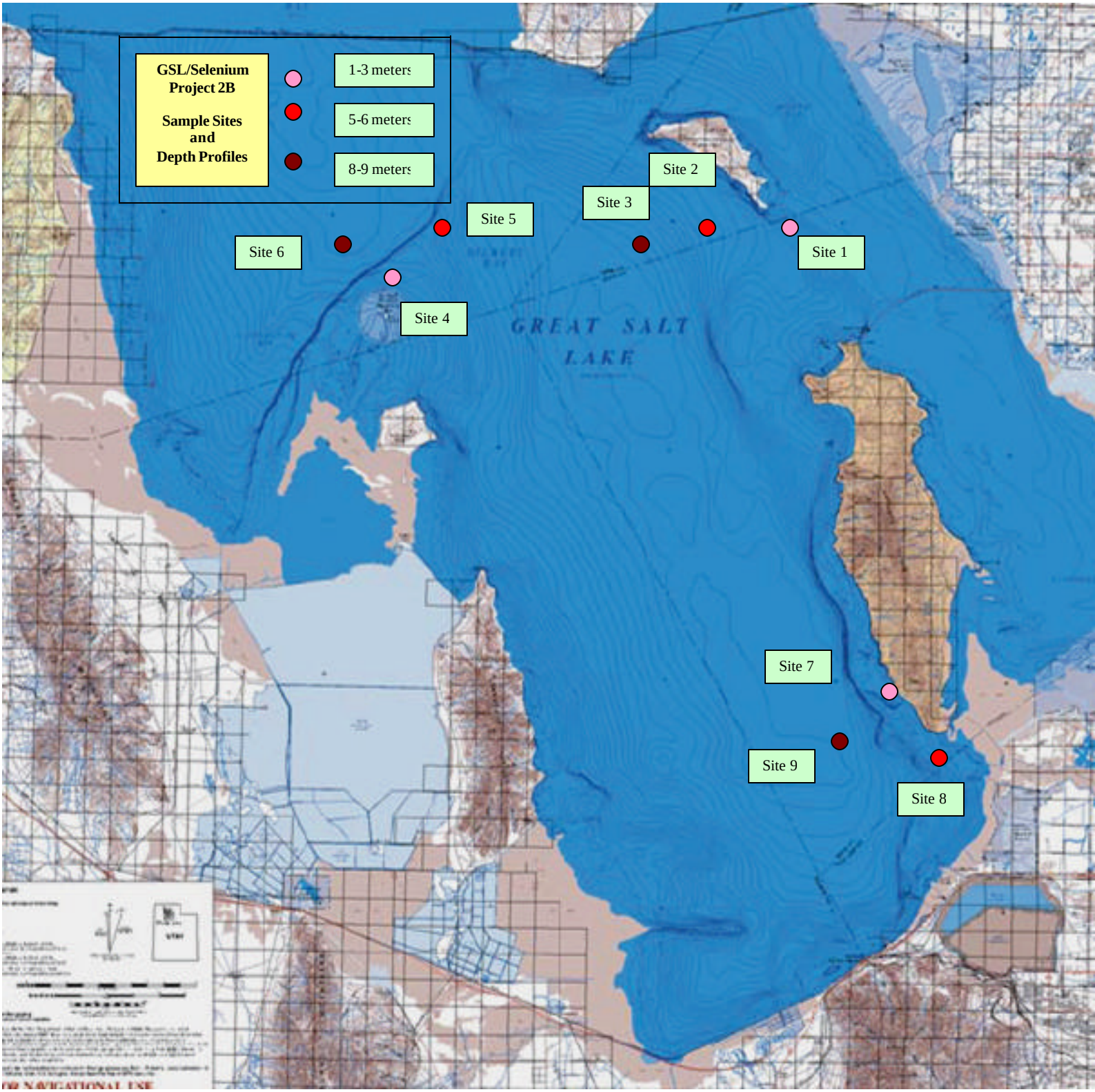


Figure 1: Great Salt Lake sample site locations. Sample locations were based on a stratified random design. Substrate composition, water depth and three geographic regions of the South Arm were used to select sample site locations.

Sampling Schedule

Sampling of the GSL began in April 2006 and has continued through August 2007. A total of 21 sampling programs were completed.

Nine sample sites were visited from April 2006 through June 2006. From July 2006 through August 2007 six sample sites were used for sample collection. This reduction in sample sizes was foreseen at the onset of the project and was implemented as a means of reducing time and analytical costs. Weather was an important consideration during the sampling programs and was a determining factor in the ability of the sampling crew to complete all sites within a sample program time period. Figure 2 depicts one of the many weather-related complications encountered on the GSL. The maximum allowable time period for a sampling program was set at 7 days. The primary objective of sampling was to complete all sampling on one sample day, or as short a period as allowable by weather, equipment function, and conditions on the GSL.

Figure 2. Extensive ice formations were encountered on the GSL during January 2007. Ice extended from Promontory Point to beyond Hat Island (sample site # 6). Diverse conditions on the GSL, such as high winds or ice sheets, rendered successful sampling at predetermined times quite challenging.

Sample collection, transport, and storage.

A summary of the samples collected is shown in Table 2. Biological and water samples were collected at each sample location. All samples were promptly stored on wet ice for transport to the laboratory. Abiotic factors were measured at each site and included temperature, dissolved oxygen, and salinity measurements at discrete intervals within the water column.

Table 2. The sampling program schedule and number of samples collected are shown. Not all samples collected have been analyzed, nor were they all intended to be analyzed. Some extra samples were collected opportunistically to expand the potential research scope of the project. Occasionally sample sizes were insufficient for analyses, or samples were not used for analysis due to budget constraints. Remaining samples are preserved by freezing (biomass), acidification and refrigeration (water samples), or with formaldehyde/Lugols iodine and refrigeration (algae samples).

Sampling Program	Sampling Dates	*Artemia* Biomass Samples	Water Samples	Seston Samples	Algae Samples	Chl-A Samples	Isotope Samples	*Artemia* Population Samples
Program 1	4/30/06	18	0	0	6	6	6	7
Program 2	5/4-12/06	42	0	0	8	8	14	14
Program 3	5/24-25/06	27	18	9	9	9	9	9
Program 4	6/12-13/06	18	0	0	6	6	6	6
Program 5	6/22-29/06	27	27	9	9	9	9	9
Program 6	7/10-13/06	18	18	6	6	6	6	6
Program 7	7/26-27/06	18	18	6	6	6	6	6
Program 8	8/18-23/06	18	18	6	6	6	6	6
Program 9	8/25-28/06	18	18	6	6	6	6	6
Program 10	9/18-24/06	18	18	6	6	6	6	6
Program 11	10/14/06	18	18	6	6	6	6	6
Program 12	11/20/06	18	18	6	6	6	6	6
Program 13	12/2/06	18	18	6	6	6	6	6
Program 14	1/26/07	18	18	6	6	6	6	6
Program 15 (Selenium Species)	3/15/07	0	0	3	3	3	0	0
Program 16	5/4-7/07	18	18	6	6	6	6	6
Program 17	5/22-23/07	18	18	6	6	6	6	6
Program 18	6/9/07	18	18	6	6	6	6	6
Program 19	6/27/07	18	18	6	6	6	6	6
Program 20	7/27/07	18	18	6	6	6	6	6
Program 21	8/21/07	12	12	4	4	4	4	4
Comparative Methods Exp.	5/8/07 & 8/31/07	18 16	0 0	0 0	0 0	0 0	0 0	0 0
Seston Filter Exp.	9/24/06	0	0	18	0	0	0	0
GSL Water Storage Exp.	7/27/06	0	8	0	0	0	0	0
SAMPLE TOTALS		**430**	**317**	**127**	**129**	**129**	**132**	**133**
GRAND TOTAL	**1,397**							

Table 3 lists the types of samples collected at each sample location, filtration (if included), replicates, preservative used, and storage conditions. Each sampling procedure is described in greater detail in Table 3.

Table 3. Sample type or matrix, analytical procedure, filtration steps, inclusion of replicate sample, preservative, and storage conditions for biological and water samples collected.

Sample Matrix/Type	Analysis	Pre-Filtration	Collection Filter	Post-Filtration	Replicate or Pooled Sample	Preservative	Storage
GSL Water	Total Selenium	Yes 125 micron	No	No	Rep.	Nitric Acid	Refrigeration[1]
GSL Water	Dissolved Selenium	Yes 0.45 micron	No	No	No	Nitric Acid	Refrigeration[1]
Seston	Total Selenium	Yes 125 micron	Yes 0.45 micron		No	None	Freezing -25 to -30° C
Artemia Biomass / Adult	Total Selenium	No	Yes 850 micron	No (2006) Yes (2007)	Pooled	None	Freezing -25 to -30° C
Artemia Biomass / Juvenile	Total Selenium	No	Yes 500 micron	No (2006) Yes (2007)	Pooled	None	Freezing -25 to -30° C
Artemia Biomass / Nauplii-Cyst	Total Selenium	No	Yes 125 micron	No (2006) Yes (2007)	Pooled	None	Freezing -25 to -30° C
Artemia Biomass	*Artemia* Population	No	Yes Plankton Net	No	Pooled	None	Refrigeration (less than 24 h)
GSL Water	Phytoplankton Population	Yes 125 micron	No	No	No	Lugol's/ Formalin	Refrigeration
GSL Water	Chlorophyll[2]	Yes 125 micron	Yes 0.45 micron	No	No	None	Freezing -25 to -30° C
GSL Water	Chlorophyll	Yes 125 micron	No	No	No	$MgCO_3$	Refrigeration

1. Water samples from May 25, 2006 to July 13, 2006 were initially stored at +5°C, but were stored at -25° C for a period of approximately 1 month.
2. Chlorophyll samples from May 4, 2006 to Oct 18, 2006 were filtered through 0.45 micron cellulose acetate filters and then stored in freezer until analyzed. Subsequent water samples were preserved with $MgCO_3$ and then promptly sent to Aquatic Research Inc. laboratory for chlorophyll analysis.

Depth intervals for sample collection and abiotic measurements.

Both biological samples and abiotic measurements were taken at specific depth intervals. Water samples were comprised of pooled samples collected at discrete depth intervals. *Artemia* samples were collected via pooled vertical, or horizontal (for the 1 meter sites only), plankton net hauls. Abiotic measurements included temperature, dissolved oxygen, and salinity. These measurements were taken at discrete intervals within the water column. The depth intervals of each abiotic measurement and biological sample collection are listed in Table 4.

Table 4. Sampling depth profile for abiotic measurements and biological sample collection.

Sample Site Depth Category	Dissolved Oxygen (discrete intervals)	Salinity (discrete intervals)	Temperature (discrete intervals)	*Artemia* for Selenium Analysis (depth from surface)	*Artemia* for Population Assessment (depth from surface)	Seston for Selenium Analysis (pooled discrete intervals)	Water Samples for Selenium, ChlA & Algae (pooled discrete intervals)
Shallow	1 m	1 m	1 m	1 m	1 m to S	1 m	1 m
Medium	1,3,5,6 m	1,3,5,6 m	1,3,5,6 m	5 m	5 m to S	1,3,5 m	1,3,5 m
Deep	1,3,5,6,7,8 m	1,3,5,6,7,8 m	1,3,5,6,7,8 m	5 m	7 m to S	1,3,5 m	1,3,5 m

Water Samples for Selenium Analysis.

Water samples were collected by means of a GeoPump™ peristaltic pump, supplied with Teflon™ lined tubing, and Masterflex® tubing. Samples were filtered through a 125-micron stainless steel sieve and collected in a 3-liter HDPE cylinder. Equivalent volumes were collected from 1, 3, and 5 meters for medium and deep sites and only from 1-meter depth from the shallow sites. Pooled volumes of GSL water were mixed thoroughly and then 250-ml samples were collected in certified and pre-cleaned HDPE or glass bottles. Water samples for dissolved selenium analysis were pre-filtered through a 0.45 micron, high-capacity cartridge filter. All tubing, bottles, and sample containers were pre-cleaned in the laboratory with DI water and a 2% solution of nitric acid. Field and method blanks were included in each sample program. Bottles were stored on ice for transport and then 2 ml of nitric acid were added to preserve solutions (pH < 2.0). Nitric acid was added within 12 hours of sample collection. Samples were then stored at 5º C until shipment for selenium analysis. Early samples (May 25 to July 13th) were initially stored at 5º C, but with delays in funding and the uncertainty of the analytical schedule were stored at -25º C. All subsequent water samples were stabilized with nitric acid and stored at 5º C until analysis.

Water Samples for Phytoplankton and Chlorophyll Analysis

Water samples used for chlorophyll analysis or for the identification and enumeration of phytoplankton were collected at discrete intervals using a 2.2-liter horizontal alpha bottle. Water samples were collected at 1, 3, and 5 meters for medium and deep sites and at 1-meter depth for the shallow sites. The water samples were filtered through a 125-micron sieve to remove zooplankton and large suspended particulates. Equivalent volumes were

collected at each depth interval providing a final volume of 1 liter each for phytoplankton and chlorophyll determination. Prior to preservation, all water samples were contained in amber Nalgene® bottles, stored on ice, and then transported to the laboratory. Water samples to be used for phytoplankton analysis were treated with Lugol's solution (0.5%) following which formaldehyde was added (1% formaldehyde). Water samples for chlorophyll analysis collected from May 4, 2006, to October 18, 2006, were vacuum-filtered through a 0.45-micron cellulose acetate filter, wrapped in foil, placed in Whirl-pak® bags and stored at -25C until being analyzed. Water samples collected after October 2006 and used for chlorophyll analysis were preserved with 1 ml per 1000 ml from a 1% stock solution of $MgCO_3$ and then refrigerated prior to shipment for analysis (usually shipped within 24-48h). Analysis of these water samples for chlorophyll was generally completed within one to two weeks of sampling.

***Artemia* Biomass for Population Assessment.**

Figure 3. Collecting brine shrimp with a plankton net.

Brine shrimp samples were collected by means of replicate vertical net hauls using a 50-cm-diameter, 165 micron mesh size, plankton net with removable collection cup (125 micron mesh size) (Figure 3). Duplicate net hauls were obtained from 1m, 5m, and 7m to the surface for shallow, medium, and deep sample sites respectively. The net haul contents were stored in 1-L Nalgene® bottles on ice and then transported to the laboratory. In the laboratory, samples were prepared by filtering the entire contents through 850-, 500-, and 125-micron sieves, resuspending in a known volume, and then replicate (n= 6 to 12) samples were obtained and counted. The volume of subsamples counted was typically 4% to 12% of the total volume. Brine shrimp were grouped according to specific age-classes: the age-classes defined for the purpose of this study included nauplii, meta-nauplii, juveniles, and adults. Cysts and empty shells were also identified and counted. Gender determination of adults was recorded as were the brood contents and brood sizes of gravid females. The dry-weight biomass for each sample was assessed. Gravid females were randomly selected, isolated, and used for brood size and characteristics determination. Ovisacs were dissected and all brood contents were identified and counted. If possible, 10 females from each site and

representing each brood type were dissected. The maximum possible number of dissections was 270 per sampling program, but fewer were often counted due to lack of adequate numbers of gravid females for each brood type. Population enumeration was completed within 24 to 36 hours of sample collection. In one exception, the biomass was stored in formaldehyde and counted later.

Artemia Biomass for Selenium Analysis.

Brine shrimp were collected via horizontal or vertical plankton net hauls. Multiple vertical net hauls were used for medium and deep sites (5-meter net hauls) whereas vertical or horizontal net hauls were employed for the 1-meter sites. The net haul contents were filtered through a sequence of three stainless steel sieves: 850-, 500-, and 125-micron opening size. Each fraction was rinsed with pre-filtered GSL water, collected in Whirl-pak® bags, and then stored on ice for transport. The samples were only rinsed with pre-filtered GSL water and never with any other source of water. In the laboratory the brine shrimp samples were poured into pre-cleaned Petri dishes where brine shrimp were carefully separated from other zooplankton or debris, water was removed via pipette, and then samples were frozen at -25º C. Samples collected during 2007 were vacuum-filtered as an additional measure to remove

Figure 4. Brine shrimp separated on the sampling vessel into three age-classes (adult, juvenile, and nauplii-cyst).

excess GSL water. All biomass samples were stored in a freezer at -25 º C until being shipped for analysis.

Figure 5. Seston filtration using Geotech polycarbonate housing and 0.45-um, 142-mm, flatstock filters.

Seston Samples.

Seston samples were extracted from GSL water collected in the manner outlined above for water samples. Pooled water samples from discrete intervals in the water column were collected via peristaltic pump and filtered to remove particulates and zooplankton greater than 125 microns. The pre-filtered GSL water was then pumped through a 0.45-micron, flatstock, cellulose acetate filter housed in a 142-mm polycarbonate in-line filter holder (Geotech) (Figure 5). The volume of water filtered generally ranged from one to five liters. The 0.45-micron filter was then removed from the filter housing, folded, placed in a Whirl-pak® bag, and stored on ice for transport. The filters were immediately placed in a freezer (-25º C) upon return to the laboratory and remained frozen until analysis. Dry filter weights were predetermined and were deducted from freeze-dried weights of the seston samples to allow for selenium determination on a dry-weight basis. Volumes filtered were used for calculations of selenium concentration in seston on a per-volume basis. Dry weights were corrected for residual salt mass on filters.

Abiotic Measurements.

Select limnological conditions, including water transparency, dissolved oxygen, temperature, and salinity, were evaluated at each sample location. Dissolved oxygen was determined using a YSI™ 550A meter calibrated to a salinity of 70 ppt (maximum possible for instrument). Dissolved oxygen was recorded at each site at depth intervals of 1 m (shallow sites), 1m, 3m, 5m, and 6m (medium depth sites), and 1m, 3m, 5m, 6m, 7m, & 8m for the "deep" sites. Dissolved oxygen is reported as both a percentage and in mg/L, Temperature and salinity were also determined and recorded at these same intervals in the water column (Figure 6.0). Salinity was assessed by means of a refractometer and temperature was obtained from a temperature probe on YSI™ 550A meter. Water transparency was recorded through observations of the final visible depth of a submerged 20-cm black-and-white Secchi disk.

Figure 6. Abiotic measurements.

Selenium Analysis in Water Samples.

All water samples were sent to Frontier GeoSciences Inc., Seattle, WA for determination of dissolved and total selenium. Total selenium included the dissolved and particulate fraction in water samples. Analytical procedures included hydride generation--atomic fluorescence (HG-AF).

Selenium Analysis of *Artemia* and Seston.

All brine shrimp samples and seston samples were sent to LET Inc. laboratory in Columbia, MO for analysis. Total selenium analysis of the biological samples was

carried out using acid digestion procedures and then hydride generation coupled with atomic absorption spectrometry. The selenium instrument detection limit was 0.01 ug and the tissue detection limit was 0.1 ug Se/g tissue. Prior to acid digestion, LET Inc. freeze-dried the samples and provided dry-weight values for each sample.

Chlorophyll Analysis.

All frozen, filtered samples used for determination of chlorophyll-a and phaeophytin concentration in phytoplankton were sent to Aquatic Research Inc. in Seattle, WA. Chlorophyll-a was determined using fluorometric methods with a detection limit of 0.1 ug Se/L.

Phytoplankton Identification and Enumeration.

Preserved phytoplankton samples were sent to the Laboratory of Ichthyology and Hydrobiology, Uzbekistan Academy of Sciences (LIH-UAS), Tashkent, Uzbekistan. Microalgae were identified to the level of family, genus, and species if possible. Results were reported in abundance per unit volume as well as the biovolume of representative algal species per volume of GSL water sampled. Identification was based on morphological features alone. Molecular markers were not used for confirmation of algal species identification. This laboratory was chosen because they have previously provided algae identification for saline lake research projects funded by NATO, in cooperation with the *Artemia* Reference Center, Ghent University, Gent, Belgium, and due to the greatly reduced analytical costs relative to laboratories in the U.S.

Samples preserved with Lugol's and formaldehyde were shipped to LIH-UAS where they were further processed and prepared for algal cell identification. Samples were vacuum-filtered through Millipore® glass fiber filters with a pore size of 0.45 microns and a 47-mm diameter. Filtered algal cells and the filter disk were placed in 47-mm Petri dishes and the cells were re-suspended by means of washing with 3 ml of distilled water. A minimum of 15 minutes of mixing was allowed for the cells to be washed from the filters. A 100-microliter aliquot was then introduced into a Palmer counting cell. Algal cells were examined at 400X to 1000X power using a Zeiss or Canon microscope with bright-field and phase-contrast optics. A 10-mm reticle was used for the enumeration and size measurements of algal cells. Identification and characterization of algal cells were taken to the species level if possible. Cell counts and biovolume measurements were conducted according to the methods of Wetzel and Likens (2000) and Hillebrand et al. (1999).

Additional supporting experiments.

Comparative study of *Artemia* sampling methods and their influence on apparent selenium concentration.

Brine shrimp were sampled concurrently using two different methods of sample collection and subsequent processing or cleaning before analysis. One method involved collecting brine shrimp, and any other debris or zooplankton, from the upper 1 meter of the GSL by hand-held plankton net. The sample was then placed in a Ziploc® bag, stored on wet ice, transported to the laboratory, frozen, and later shipped in a frozen condition to LET Inc. for analysis of dry weight and selenium content. No subsequent processing was included. The alternative method included the procedures defined

previously for sampling and processing *Artemia* for selenium analysis. Specifically, samples were collected from the water column by plankton net, filtered through tiered stainless steel sieves (850-, 500-, and 125-micron), placed in Whirl-pak® bags, stored on ice, and transported to the laboratory. The samples were then separated from any incidental debris or other zooplankton. The cleaned samples were then split into two fractions: those placed directly into Whirl-pak® bags and frozen, versus those that were subsequently vacuum-filtered to remove excess GSL water before freezing. The resulting biomass samples were stored at -25º C until analyzed by LET Inc. for total selenium and dry weight.

Influence of storage conditions on selenium determination in water samples.

Replicate water samples were collected, acidified, and then stored either in a refrigerator (+5º C) or in a freezer (-25º C). The purpose of this small study was to determine if storage conditions exerted any influence on selenium determination in GSL water samples.

Comparative study of three different flatstock filters for the collection of seston and subsequent determination of total selenium.

Suggestions for trying alternative filter types for the collection of seston arose during the course of this study. Other researchers have tried a variety of flatstock filter types and pore sizes for the purpose of collecting seston from water samples. Three different filters were used for the study: 0.45- and 0.8-micron cellulose acetate filters and 0.45-micron polycarbonate filters. All filters were 142-mm filters and were housed in a GeoTech

polycarbonate filter housing. On the day of the test, raw GSL water from the selected depth was pumped through each filter until the filter was clogged. Filters were removed, placed in pre-cleaned petri dishes then Ziploc® bags, and stored on wet ice for transport. The filters were promptly frozen at -25º C and remained frozen until being analyzed for total selenium by LET Inc.

RESULTS and DISCUSSION

Sampling Schedule

The final sampling schedule was a result of defining sampling dates and then making every effort possible to complete a sampling program within 7 days of the target date. Although occasional equipment malfunctions caused some delays, these seldom resulted in a delay of more than 1 day, and were usually attributable to the complications of working in a hypersaline environment. Weather was the main factor influencing the duration of a sampling program and in the ability to complete a full sampling program on, or near, the proposed date. There were notable occasions in which the winds increased dramatically, and all sampling efforts had to be abandoned for the day. The most memorable of those occurred in July 2006, when the wind speed near Hat Island increased from 10 - 15 mph to 77 mph in about 35 minutes. During the January 2007 sampling program, extensive sheets of ice (sufficiently thick to support the weight of a rapidly scurrying human) were present from Promontory Point to our sampling sites north of Hat Island (Figure 2). Needless to say, sampling under these conditions was less than optimal.

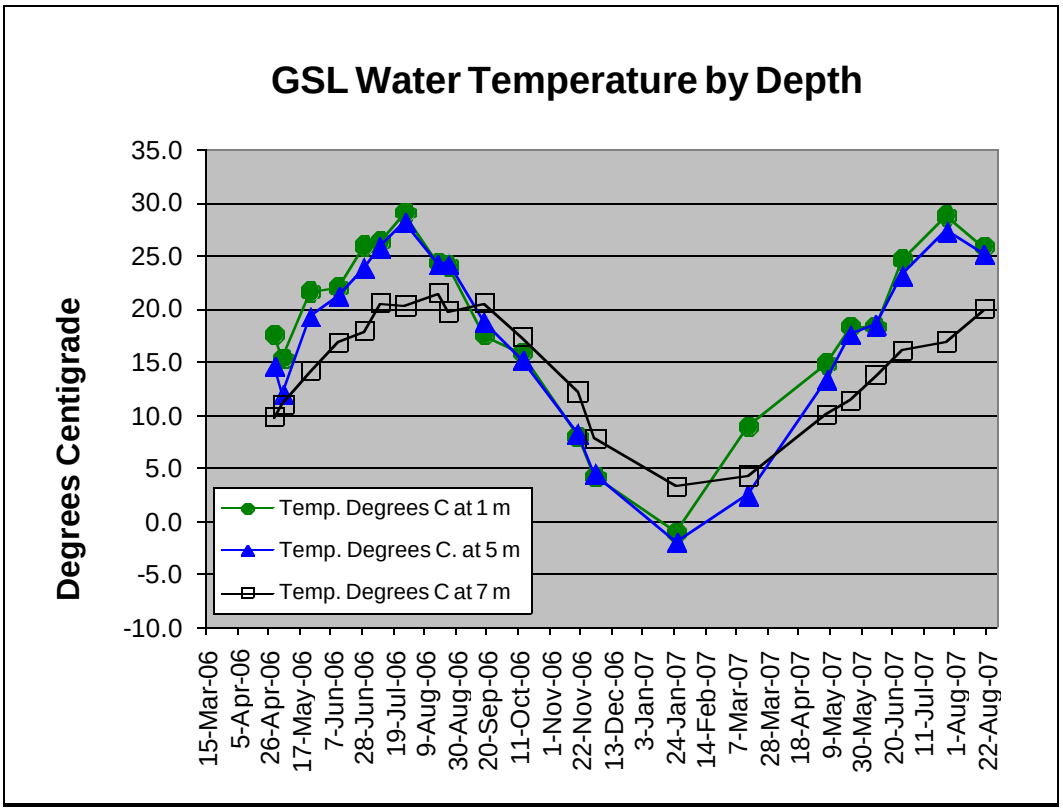
Limnological Conditions.

Water Temperature.

Water temperature was monitored at discrete intervals in the water column throughout this study (Figure 7). During the earliest sampling program in April 2006 the water temperature at 1 meter was already in excess of 15°C. This is about 8°C to 10°C above the typical threshold for the onset of *Artemia* hatching in spring. The temperature of the GSL at 1-m depth increased throughout the summer of 2006 reaching a maximum of 29.0°C on July 27, 2006. The temperature then declined throughout the fall and into winter reaching a minimum temperature of -1.1°C on January 26, 2007. During the winter of 2007, there were extensive sections of ice on the surface of the GSL ranging from 3 to 7 cm thick. The surface temperature again warmed to over 9°C on March 14, 2007 and the most recent temperature on June 9, 2007 was 18.3°C. The deep brine layer typically responds more slowly to warming and cooling than is exhibited in the upper "mixed zone" of the GSL. The deep brine layer remained cooler than the upper mixed layers throughout the spring and summer until September 18, 2006. On this date the upper layer had cooled to 18.7°C whereas the deep brine layer remained almost two degrees warmer (20.5°C). The deep brine layer reached a minimum temperature of 3.3°C during January 2007 and continued to be warmer than the upper layer until March 2007 when the upper mixed zone had warmed to 8.9°C and the deep brine layer was still only 4.3°C.

The results seen in Figure 7 demonstrate the significant interannual variability in water temperature patterns for the GSL.

Figure 7. Water temperature of the GSL from April 2006 through August 2007. Temperature was recorded at three different depth intervals (1 m, 3 m, and 7 m).

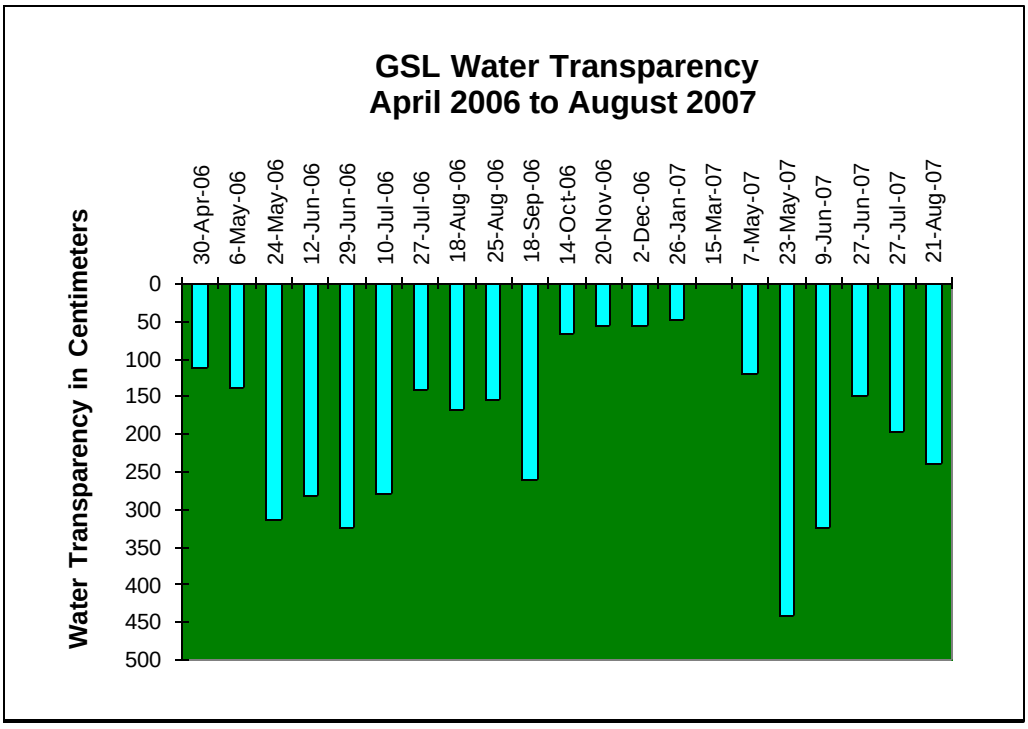


Water Transparency.

Water transparency during spring and summer 2006 varied from an average low in April 2006 of 112 cm to a maximum average depth of 324 cm in June 2006 (Figure 8). During the summer and fall of 2006 the GSL exhibited a characteristic pattern of cyclical changes in water transparency, largely attributable to the grazing pressure exerted on the algal population by the brine shrimp. Wind events and suspended particulate matter also influenced water transparency measurements. Following the brine shrimp population collapse in the winter of 2006-2007 the algal population once again flourished, obscuring visibility and resulting in a minimal water transparency of 47 cm during January 2007.

As the brine shrimp population expanded in the spring of 2007 grazing pressure on the algal population again increased dramatically and resulted in quite clear conditions with average water transparency values exceeding 440 cm in May 2007.

Figure 8. Water transparency of the GSL in centimeters. Measurements correspond to average transparency as measured by the final visible depth of a 20-cm diameter Secchi disk.

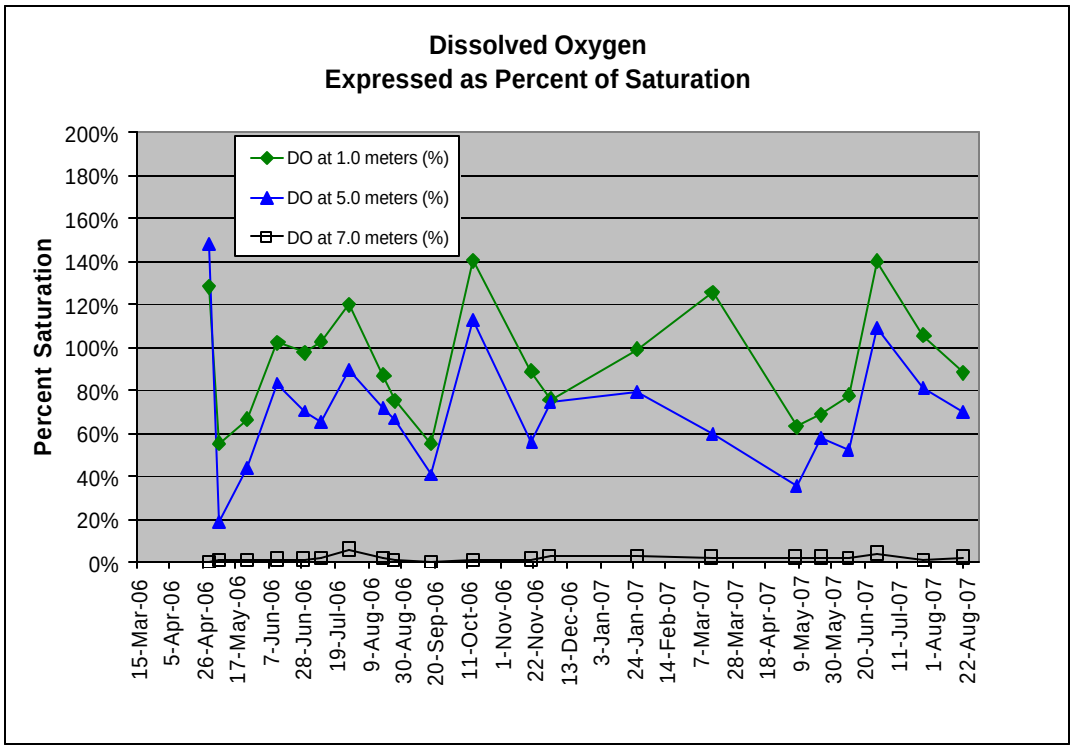


Dissolved Oxygen

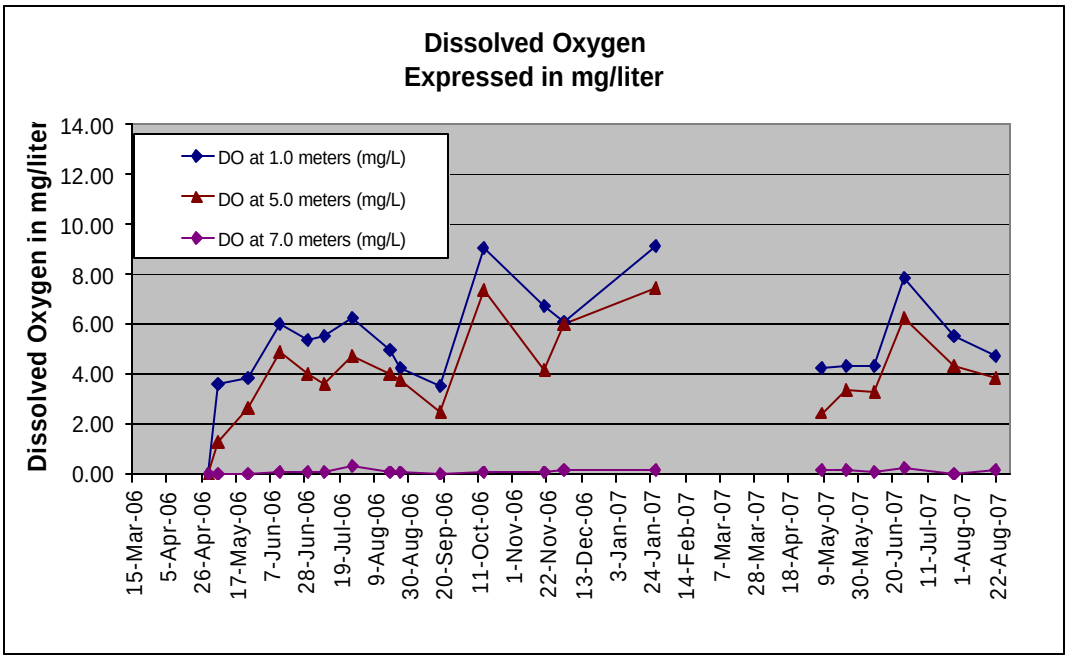
Dissolved oxygen followed a roughly inverse relationship to water transparency--at low Secchi disk measurements, and relatively high algal abundance, oxygen values were elevated. When the *Artemia* population expanded, algae were effectively depleted, transparency increased and dissolved oxygen was reduced. Dissolved oxygen in the upper mixed zone ranged from a high of 120% to 140% of saturation (Figure 9). Low

values typically observed at mid-depth during April and May were in the range of 20% to 40% of saturation. Characteristic fluctuations at shallow and mid-depth during the summer and fall months were generally between lows of 40% to highs of 80% saturation. Site-specific differences were present, the most notable of which was sample site #4 (Hat Island), which typically exhibited the highest average dissolved oxygen levels (range 55% to 216%). The deep brine layer remained anoxic throughout the study, as anticipated given the chemical composition of this layer. The transition from the upper mixed zone into the deep brine layer was quite abrupt, occurring between 6 and 6.5 m in depth. The average dissolved oxygen at 6 m was 61.2% whereas the average at 7 m was only 1.8% (Appendix 1.1). Dissolved oxygen values are also shown in mg/L (Figure 10). However, there are instrument limitations when the salinity is greater than 70 ppt that reduce the reliability of the conversion to mg/L oxygen.

Figure 9. Dissolved oxygen in the GSL at three different depths reported as percent saturation



. Figure 10. Dissolved oxygen in the GSL at three different depths reported as mg/L

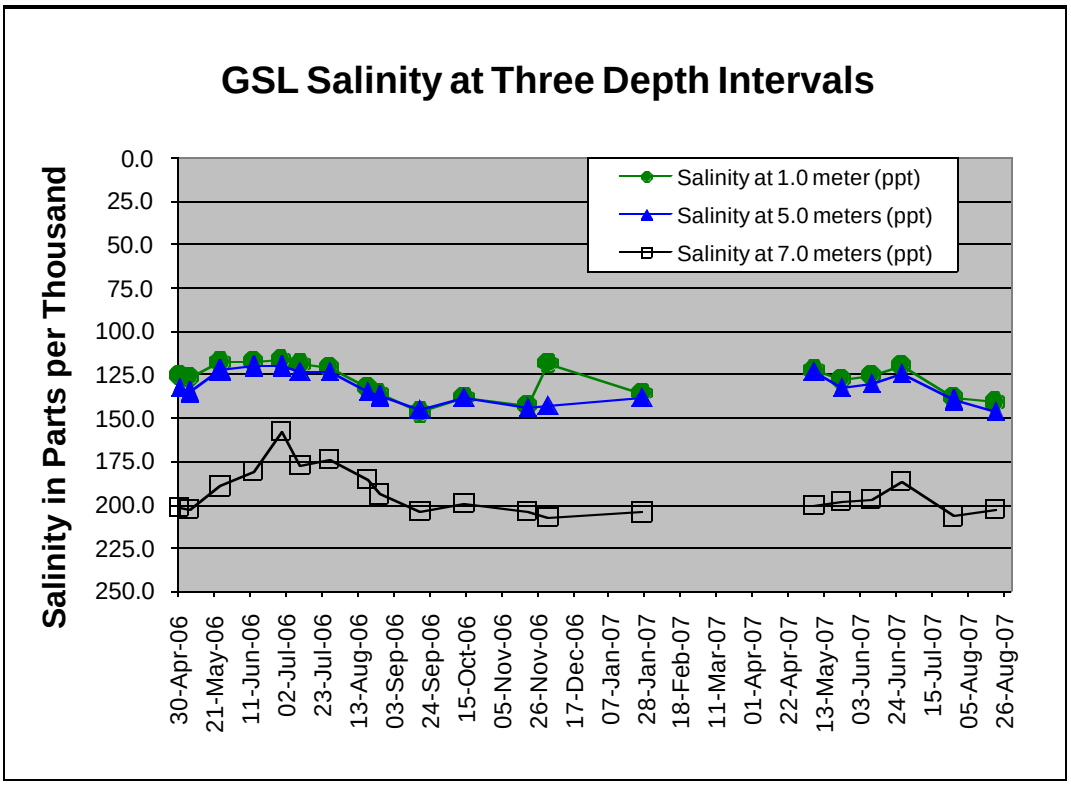


Salinity

Salinity was recorded at 6 different intervals (1 m, 3 m, 5 m, 6 m, 7 m, and 8 m) in the water column throughout this study. The upper 5 m (surface to 5 m depth) was quite uniform spatially across the GSL within each sampling program (Figure 11 and Appendix 1.1). The data indicate seasonal patterns of stratification and mixing of the upper zone of the GSL (the mixolimnion) combined with the presence of meromictic conditions (chemical barrier to deep mixing) in areas of the lake with an established deep brine layer (the monimolimnion). Evidence of exchange of the deep brine monimolimnion layer with the upper "mixing zone" begins to be apparent below 6 m depth. The salinity for the upper 5 m of the water column ranged from a minimum of 110 to a high of 150, whereas at 7 m in depth the range was 120.2 to 225.0 ppt. This was a similar pattern as observed

for dissolved oxygen in which the meromictic transition zone was usually evident below 6 m in depth (Appendix 1.1).

Figure 11. Salinity of GSL water samples as measured by refractometer. Three of six sampling depths are represented. The influence of inflow of saturated brine from the North Arm of the GSL is evident in the dramatic increase in the water column salinity at 7 m (not shown) and 8 m depths.



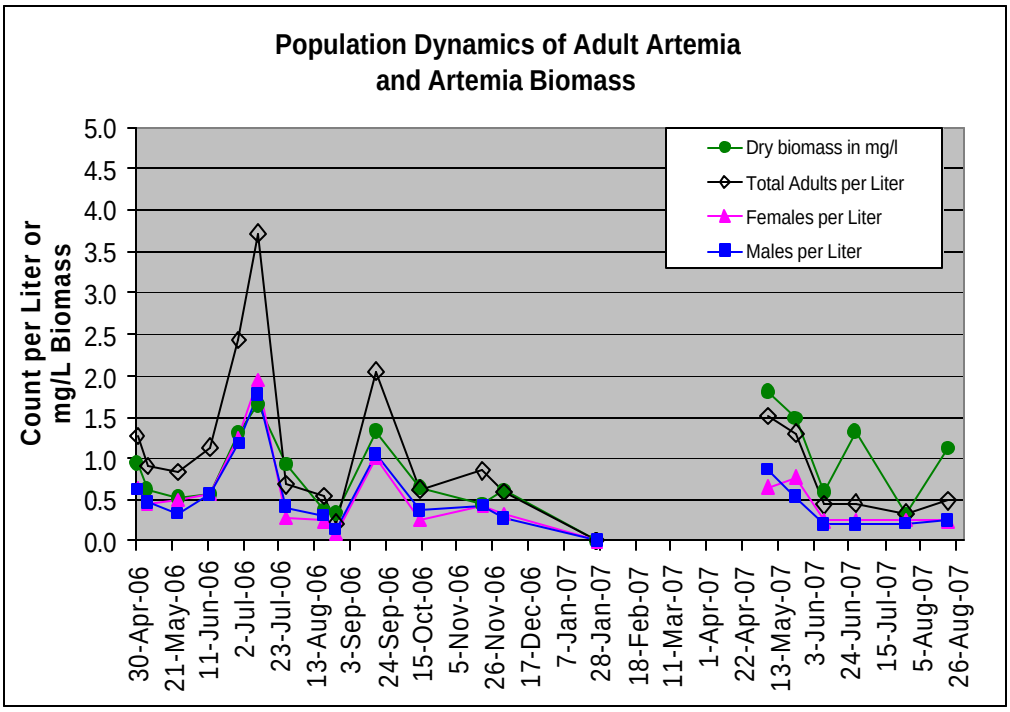
Brine Shrimp Population Dynamics.

Detailed brine shrimp population dynamics were assessed during this study because of the importance of brine shrimp as a critical component in the food web of the GSL and their role in the trophic transfer of selenium from the water to wildlife. Brine shrimp used for population assessments were collected from the water column extending from the surface to 7 m in depth. Although few brine shrimp are found below 6 m in depth

relative to those in the first 5 m of the water column, the upper layers of the monimolimnion were included in the brine shrimp population assessment because previous studies have shown that cyst abundance at the chemocline between the upper mixing zone and the deep brine layer can be quite substantial (Stephens, 1997). Brine shrimp were separated by size filtration and then counted in the laboratory to determine age-specific abundance (developmental instar stages) and reproductive status (brood contents and sizes). Although filtration provided reasonably adequate separation of age-classes, all samples were carefully counted under a binocular microscope to assure that age-class determination was based on morphological features and not defined solely by size distribution.

In the GSL, overwintering brine shrimp typically hatch during March and April, producing the first generation of nauplii for the reproductive season. During this study the frequency and timing of sampling resulted in our inability to specifically identify the onset of hatching and the full reproductive dynamics of the first generation. Samples collected during the first sampling program for the spring of 2006 (April 30) and 2007 (May 7) revealed that the first generation of brine shrimp were already established across all age-classes and the production of a second generation was well underway (Figure 12). Adult abundance was 0.2 to 2.0 adults per liter in April, and average adult abundance was usually between 0.2 and2.0 individuals per liter for the remainder of the reproductive season (Appendices 2, 3, & 4).

Figure 12. Adult *Artemia* population dynamics for the GSL during April 2006 to June 2007. Dry biomass expressed as mg/L is also shown and includes all age-classes of *Artemia*.



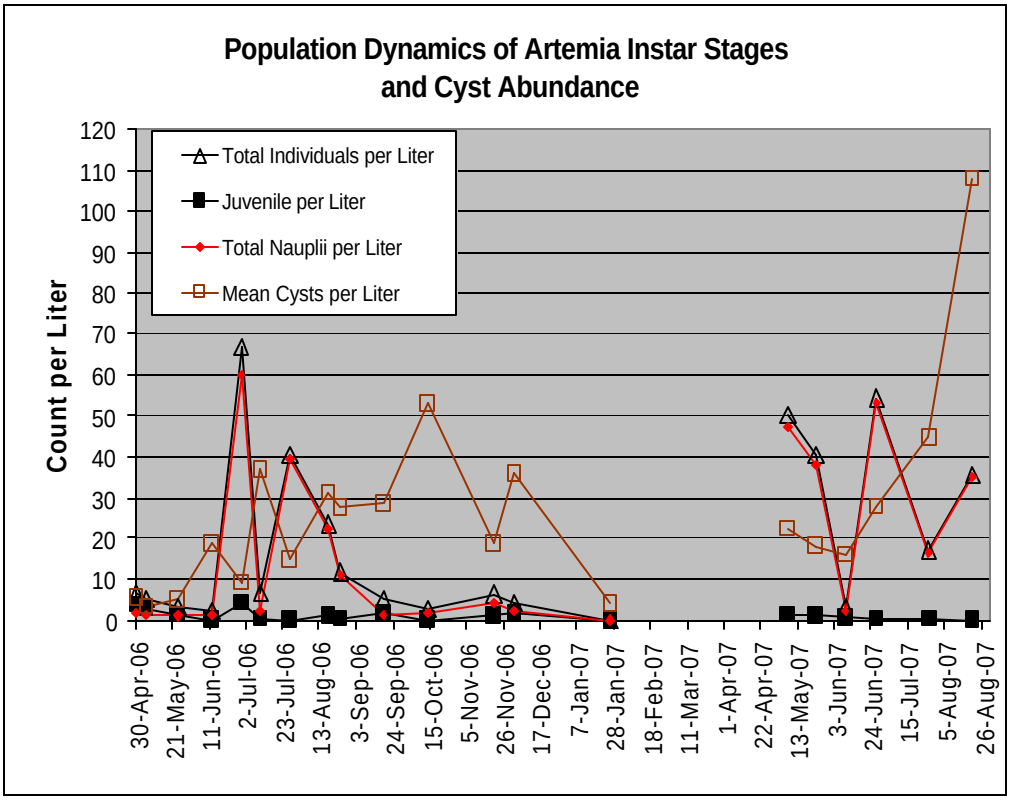
The sex ratio of adult *Artemia franciscana* varies within specific time periods, but over the course of the reproductive season the average remains close to a 1:1 ratio—the ratio of males:females over the course of this study was 1.19:1.00. Sex ratio is an important consideration for the GSL as there have been some concerns about the introduction of foreign *Artemia* (e.g., parthenogenetic species) into the GSL. A change in the sex ratio could be an important indicator of a shift in the genetic composition of the GSL *Artemia* population. The results of this study are consistent with a bisexual *Artemia* population.

There are typically between 3 and 5 identifiable generations in the brine shrimp population during the reproductive season, and in our study this pattern was also observed. Peak abundance of combined nauplii (nauplii and meta-nauplii) occurred in April, June, July, and August (Figure 13). There may have been one earlier F1 nauplii abundance spike in

April that was not recorded---the onset of our sampling schedule was likely too late to have recorded the initial synchronous hatching of cysts and production of F1 nauplii. The highest count of combined nauplii that we observed occurred on June 29th with a count of 60.1/L. Peak abundance of combined nauplii in May and June corresponds to the maximal reproductive output of the first generation. There was a slight increase in the number of combined nauplii per liter in November (4.36/L). This is somewhat unusual as the abundance of the younger age-classes of *Artemia* generally falls below 1/L in October due to the predominant shift from ovoviviparity to oviparous reproduction and rapidly decreasing water temperature. Juvenile brine shrimp exhibited a similar pattern as the combined nauplii in terms of the cycles of abundance, albeit on a much lower scale, and with an altered temporal component. Peak juvenile abundance was observed during the first two sampling programs (April 30 and May 6, 2006), then on June 29, September 18, and again at the end of November and early December. On December 2, 2006, 1.8 juveniles/L were counted. It is quite surprising to document an abundance of >1.0 juvenile/L at this time of year because juvenile brine shrimp are the least tolerant of environmental stressors (Belovsky, 2006). Adults can remain viable on the GSL well into December, and in the current study adult brine shrimp were still present on

December 2, 2006. By January 26, 2006, no live brine shrimp were observed at any of the sample locations.

Figure 13. Juvenile, combined nauplii, and cyst abundance for the GSL from April 2006 to June 2007. Cyclical patterns of production, survival, and collapse are evident. Predominant cyst production is initiated in July and continues into early winter. Cyst depletion from October to January is largely attributable to industry harvesting pressure.



Cyst abundance in the GSL during 2006 ranged from a low of 3.3/L on May 6 to a high of 53.0/L on October 14 (Figure 13). The April 30 count was slightly higher (5.3/L) than the May 6 count, and this coincides with an increase in the number of nauplii per liter from April 30 to May 6, suggesting that overwintering cysts were still viable and continued to hatch during early May. Cyst abundance increased sharply in July as the

shift from ovoviviparous reproduction to oviparity began. Brood counts were initiated only after the shift to oviparity was observed. This was done as a means of tracking cyst production from July through the onset of winter.

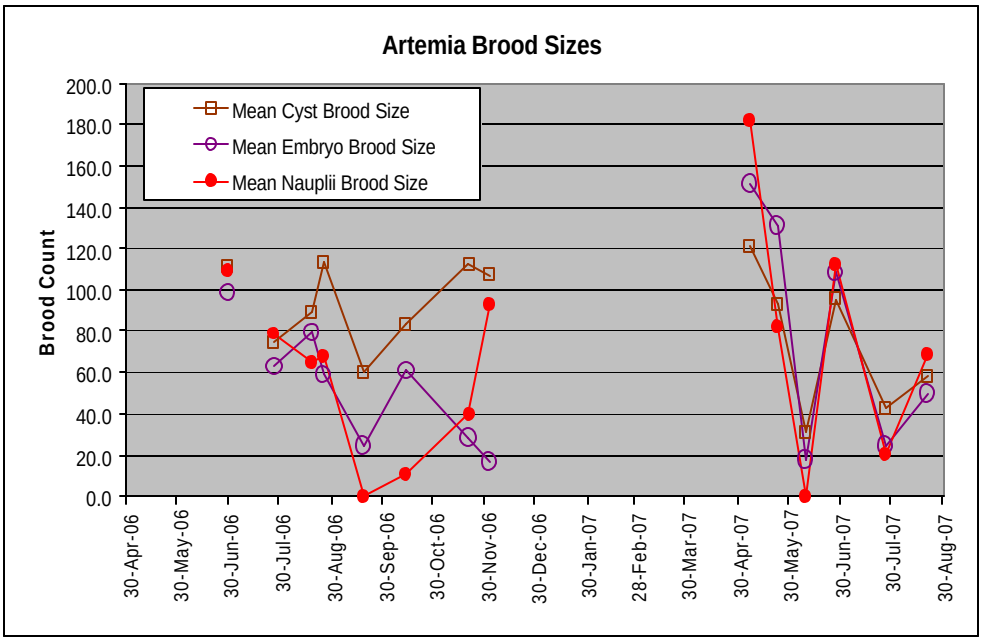
Brine Shrimp Fecundity and Cyst Production.

Fecundity (e.g., cyst production) during the summer and fall is an important measure of individual fitness—the ability to produce viable offspring and propagate one's genetic information. It is also one of the dominant factors influencing population dynamics in the subsequent reproductive season. Intact brood contents (Figure 14) were evaluated for brood size and brood characteristics (i.e., embryo, cyst, or nauplii production).

Figure 14. Female *Artemia* with intact broods. Brood contents can be observed under a dissecting microscope. In the image below, ovisacs are visible with cysts (brown spheres) and live young (pale-yellow). Individual females are randomly selected, the ovisac is dissected, brood contents are identified and counted. Brood contents are characterized as embryos, cysts, or nauplii. Undifferentiated embryos were also noted and recorded. Any brood abnormalities were documented. Retrieved July 2006 from http://www.wildlife.utah.gov/gsl/brineshrimp/

Cyst brood sizes in 2006 ranged from 60 (September) to 114 (August) and 112 (November) (Figure 15). Females reproducing ovoviviparously exhibited a range of brood sizes between 109 (June) to 11 (September) nauplii per brood. Oviparous reproduction predominated from July until winter, with very low numbers (<0.01/L) of ovoviviparous females observed from September through December. Peak brood sizes in 2007 occurred in May, with maximum average size of 121 cysts per ovisac on May 7. Ovoviviparous reproduction also showed very high per capita reproductive potential on May 7—the average nauplii brood size was 182 nauplii per ovisac. Brood sizes diminished substantially in June 2007 for both ovoviviparous and oviparous females; brood sizes were less than 50 offspring per female. Brood sizes among ovoviviparous females showed a similar pattern as oviparous females, albeit usually smaller average sizes (80%) than cyst broods. There was one exception on May 7 in which nauplii brood sizes were 50% larger than corresponding cyst brood sizes.

Figure 15. *Artemia* brood sizes from June 2006 to August 2007. Broods were characterized as containing embryos, nauplii, or cysts. Brood contents were counted from a subset of females from each sample location



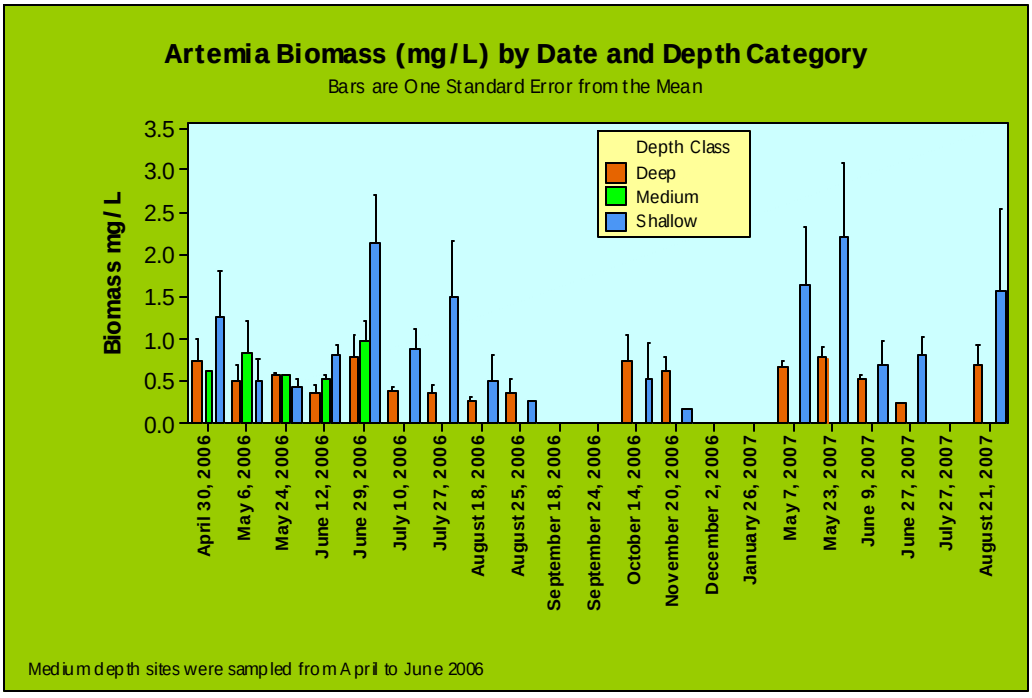
Productivity, defined as cysts per ovisac multiplied by the number of oviparous females per cubic meter, is a useful measure of the reproductive potential of the population at a given time and location on the GSL. Productivity in 2006 peaked on June 29, July 27, and then again on October 14. The maximal productivity measured in this study occurred on July 27 at 14,270 additional cysts per cubic meter. Sustained productivity was observed throughout the late fall and onset of winter. On December 2, 2006, the *Artemia* population still had a productivity count of 3,119 additional cysts per cubic meter. By January the productivity index for the population was zero. During the spring of 2007 both ovoviviparous and oviparous females were present. Productivity on May 23, 2007, was 2,643 additional cysts per cubic meter. No measure of productivity for May 7, 2007,

was available, although oviparous females were present and the average cysts brood size was 121 cysts per ovisac. The sharp decline in brood sizes during late May and June 2007 corresponds to low chlorophyll concentrations in the water column (chlorophyll-a < 2.0 ug Se/L).

Brine Shrimp Biomass.

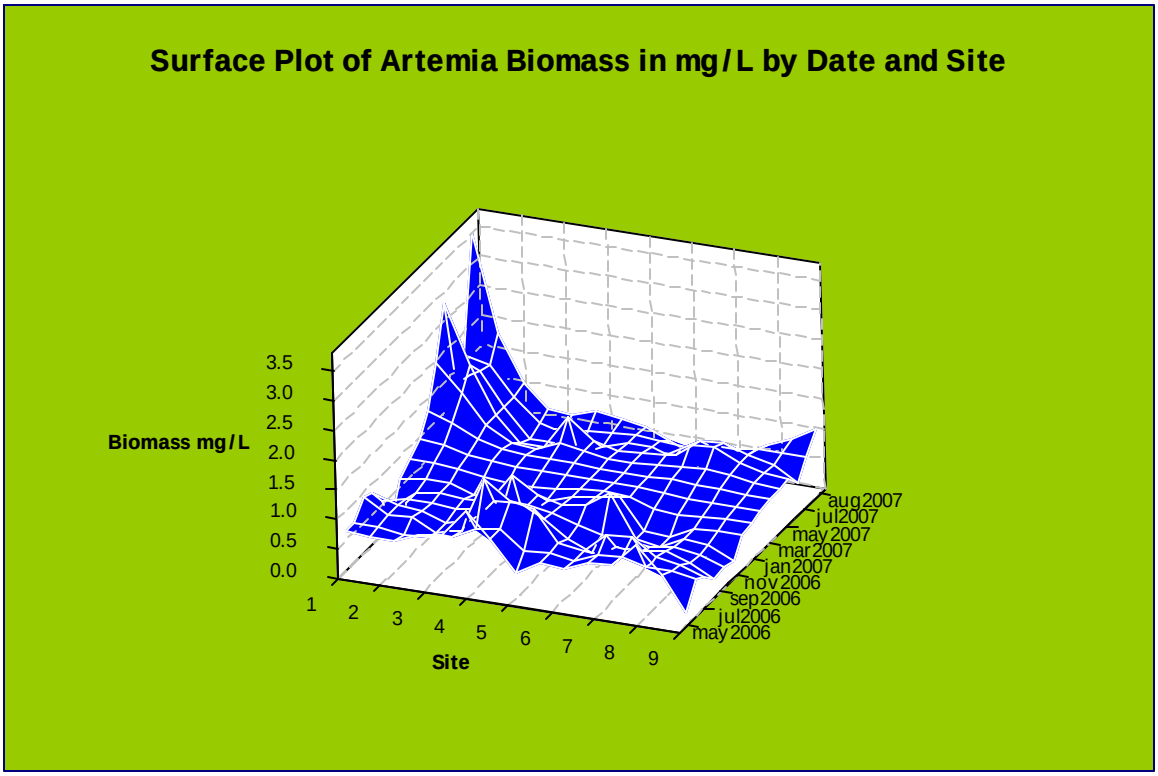
Artemia biomass, and its availability to foraging birds, is perhaps the most relevant statistic to consider in terms of the application of *Artemia* population statistics to an inquiry of selenium impacts on GSL biota, and the transfer of selenium through the food web.,. *Artemia* biomass in 2006 ranged from a low of 0.33 mg/L on August 25 to a high of 1.65 mg/L on July 10. During the spring of 2007 a peak of 1.80 mg/L was recorded on May 7. Biomass decreased to 1.48 mg/L on May 23 and continued decreasing to 0.60 mg/L by June 9 (Figure 16). This decrease corresponded with increasing water transparency and grazing of phytoplankton. Over this same time period in 2007 chlorophyll decreased from an average of 7.5 ug Se/L (maximum of 15.0 ug Se/L) to 1.6 ug Se/L (maximum of 2.1 ug Se/L).

Figure 16. The temporal pattern of brine shrimp biomass is shown from April 2006 to August 2007. Biomass was determined empirically by drying and weighing a subsample of *Artemia* biomass from every sample location and sampling program. Biomass was not estimated using literature values of average *Artemia* dry weights and then extrapolating using population statistics. Biomass values represent the average distribution in the water column, but may be well below values found in patchy accumulations of floating shrimp or cysts.



A three-dimensional plot of biomass by sample site and date is shown in Figure 17. The shallow sites #1 (Fremont Island site) and #4 (Hat Island) were the highest in biomass production per cubic meter of the sites sampled in this study. Dense accumulations of floating shrimp (?)biomass and cysts were observed throughout this study, but were not included in the determination of biomass. All samples for biomass determination were taken from water column samples and computed on a volumetric density basis. Birds were commonly seen foraging on surface accumulations of shrimp (?) or cysts, especially in the area close to Hat Island.

Figure 17. Three-dimensional relationship of *Artemia* biomass, sample site, and date of sampling program. Shallow sites were generally more productive than deep or medium depth locations.



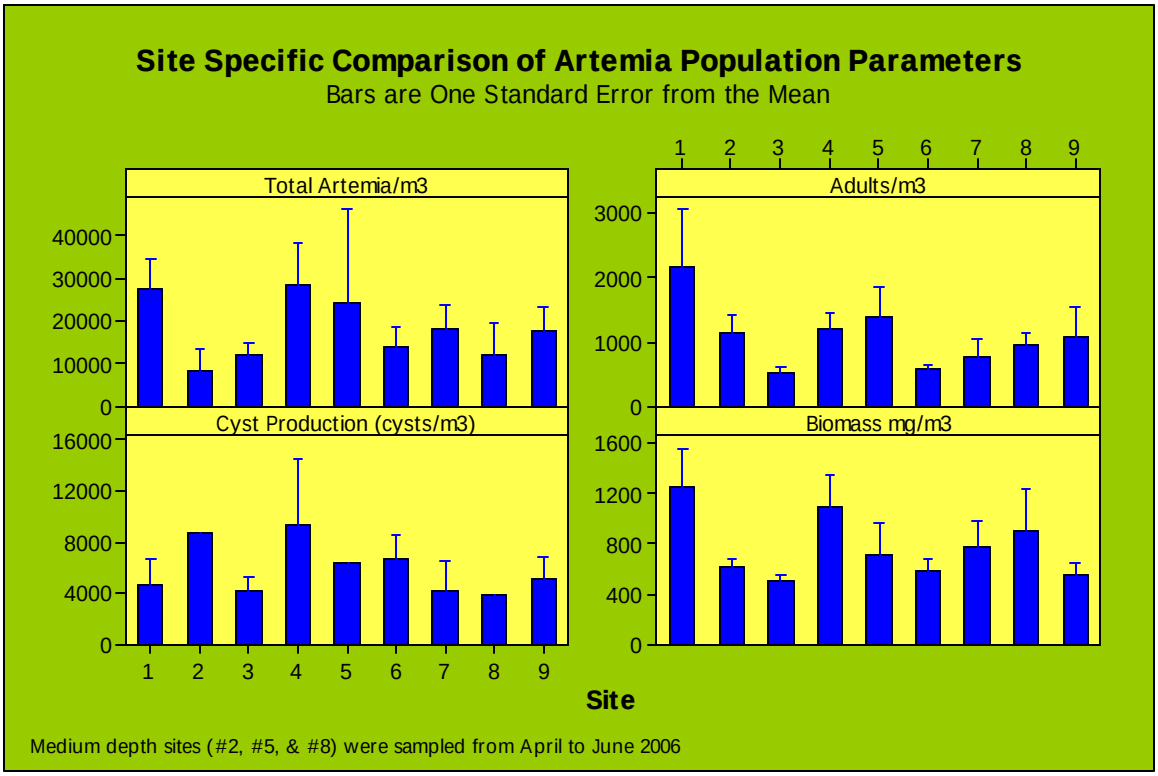
Although it is well documented that there are pronounced temporal changes in zooplankton and phytoplankton abundance on the GSL, it is not established whether there is a spatial component influencing population dynamics. From a conceptual standpoint,there should be differences spatially—the lake has distinct localized input sources, hydrochemical characteristics, currents, depths, and other physical and chemical features that should exert an influence on phytoplankton and zooplankton growth, survival, and reproduction. However, brine shrimp are mobile organisms and can propel themselves throughout the water column (although they do use their locomotion primarily for foraging). Brine shrimp are also certainly subjected to the movements of

the many pronounced currents, mixing zones, thermal and density cycling events, and wind-related disturbances that are commonplace at the GSL.

The many aspects of movement by the brine shrimp throughout the GSL add important elements of uncertainty when evaluating population and selenium results within a spatial context—the collection of brine shrimp that may be found in a given location on a particular sampling date may be transported to a distant location on subsequent days. The uncertain movement of brine shrimp needs to be considered as confounding any interpretation of spatial results.

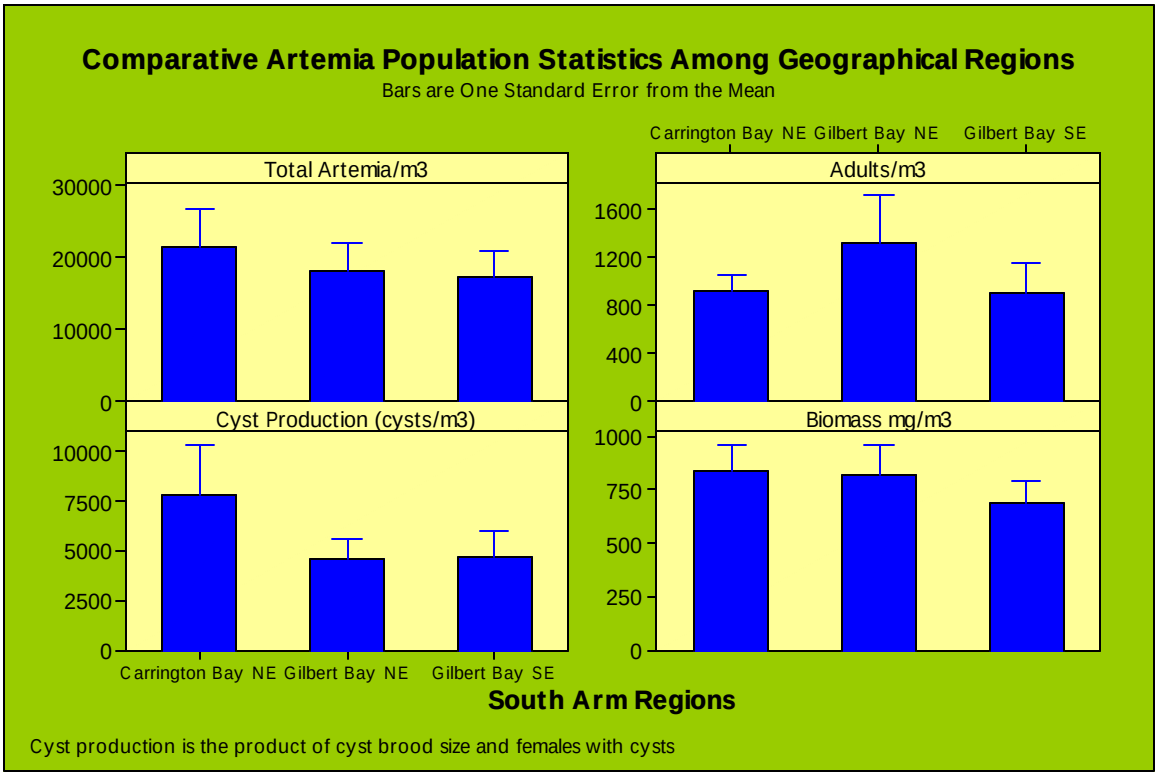
Parameters of *Artemia* population size, composition, and reproductive output were compared on a site-specific basis and across geographic locations. The results are detailed in Appendix 6.1 for each sample site surveyed and are shown in Figure 18.

Figure 18. Site-specific statistics for measures of *Artemia* population structure, biomass, and reproductive output. There are apparent differences among specific sample sites in terms of the brine shrimp population size and productivity.



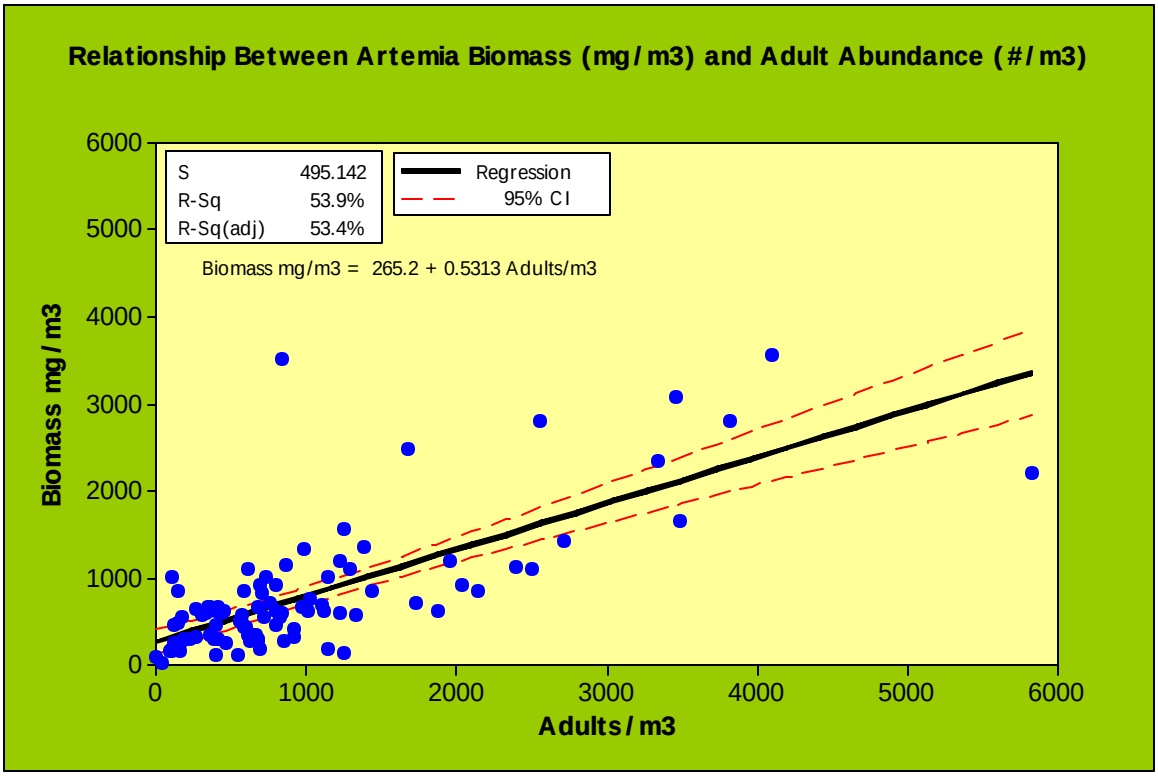
Statistical analyses were grouped across geographic regions. There were no statistically significant differences across these spatial categories (Northeast, Central, Southeast) for cysts per brood (P=0.784; df: 2, 65), biomass (P=0.457; df: 2, 90), productivity (P=0.624; df: 2, 61), or adults/m^3 (P=0.874; df: 2, 113). Descriptive statistics for these regions are shown graphically in Figure 19.

Figure 19. *Artemia* population statistics presented in terms of spatially distinct regions of the GSL. Average results for various measures of *Artemia* biology were examined over the summer and fall months of 2006. Population and reproductive data grouped according to these spatial categories were not statistically separable.



Although all age-classes were used for the biomass calculation, adult abundance was the best predictor of biomass--there is a positive linear correlation ($R^2 = 0.66$) between adult abundance (adults/L) and biomass (mg/L) (Figure 20). Individual adult weights were estimated by deducting nauplii and juvenile biomass from total biomass and then calculating the biomass per adult. The results of this estimate showed average adult biomass of 0.864 mg/adult ($\pm$ 0.636). The average weight of all individuals was 0.138 mg/individual brine shrimp.

Figure 20. Counts of adult brine shrimp per cubic meter allow for predictions of biomass in the GSL. Although the total count of all age-classes of brine shrimp is also correlated with biomass weight, the counts for adults provide a more reliable relationship and predictive equation.



Water depth influences nutrient cycling, temperature regulation, light penetration, zooplankton and phytoplankton growth and productivity. Because of this, *Artemia* reproductive and biomass statistics are compared across depth categories (Figure 21). Average values for biomass and productivity suggest that shallow sites are more productive for *Artemia* than deep sites (Tables 5, 6, and 7). However, a T-test comparing means between deep and shallow sites does not show statistically significant differences for cyst brood size ($P = 0.252$, df: 1, 65), productivity ($P = 0.674$, df: 1, 49), or biomass ($P = 0.394$, df: 1, 64). There was, however, a significant difference between deep and

shallow sites in the average number of adults per cubic meter (P=0.052; df: 1, 91): shallow sites had a greater number of adults/m3. It is possible that stromatolites and their resident population of benthic algae offer an alternative food supply for *Artemia* during times of over-grazing of the phytoplankton in the upper water column. This would provide an advantage for *Artemia* exploiting shallow sites rather than deep sites.

In comparison to all other sites, sample site #4 (shallow site near Hat Island) was uniquely an area of high phytoplankton and *Artemia* productivity. This site was typically 20% to 50% higher than other sites in measures of reproductive output, population size, and biomass. The Hat Island shallow site had the highest overall productivity per cubic meter (11,205 additional cysts per cubic meter), the highest average number of *Artemia* per cubic meter (27,001 brine shrimp/m3), the most biomass (1.158 mg/L), and consistently had the highest average (113.7%), minimum (55.5%), and maximum (214.0%) dissolved oxygen percentages. This site has been observed in past GSL research projects to be among the most productive of locations surveyed on the GSL. This location is near the gull colony on Hat Island and is therefore of interest when considering availability of *Artemia* for the diets of gulls and other avian species utilizing Hat Island.

Figure 21. Cyst brood size, productivity, and biomass results for Great Salt Lake *Artemia* population during May 2006 to June 2007. Statistics are presented in terms of depth category (shallow, medium, deep). Shallow and deep sites were included throughout the study. Medium depth sites were included only from April until June 2006.

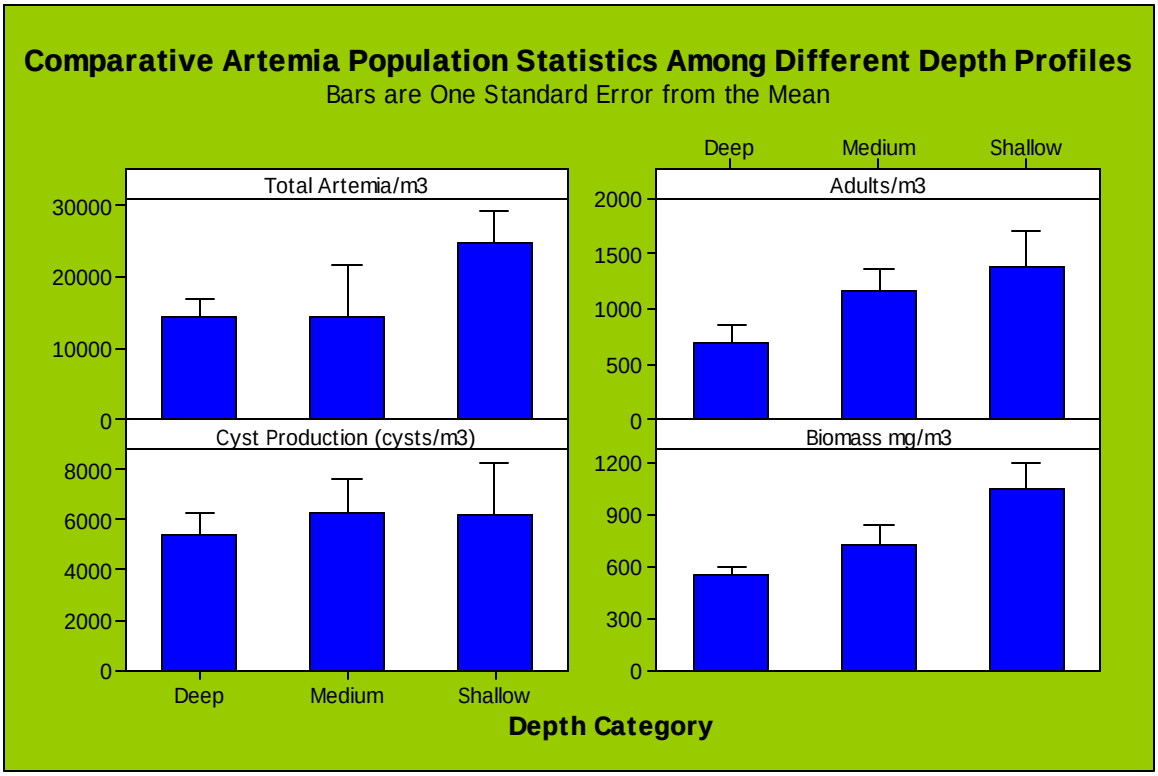


Table 5. Great Salt Lake *Artemia* biomass in mg dry weight per liter.

Artemia Biomass in mg/L by Depth Category						
		April 2006 to June 2007				
SITE	MEAN	STD DEV	CV	MIN	MAX	N
Deep	0.642	0.689	107.30	0.17	4.50	52
Medium	0.727	0.380	52.26	0.34	1.56	12
Shallow	1.181	1.355	114.70	0.02	7.03	52

Table 6. Average cyst brood size among oviparous female *Artemia.*

Cyst Brood Size by Depth Category						
		April 2006 to June 2007				
SITE	MEAN	STD DEV	CV	MIN	MAX	N
Deep	91	34	38	27	157	35
Medium	104	10	9	93	112	3
Shallow	81	34	42	24	154	30

Table 7. Fecundity estimates of *Artemia* reported as cyst brood size x number of females carrying encysted eggs in their ovisac.

Productivity per Cubic Meter (cyst brood size x # females w/cysts) by Depth Category						
		April 2006 to June 2007				
SITE	MEAN	STD DEV	CV	MIN	MAX	N
Deep	4,580	5,672	124	27	23,871	35
Medium	6,324	2,371	37	3,950	8,692	3
Shallow	6,562	13,565	207	28	69,450	30

Cyst Abundance, Harvest Yield.

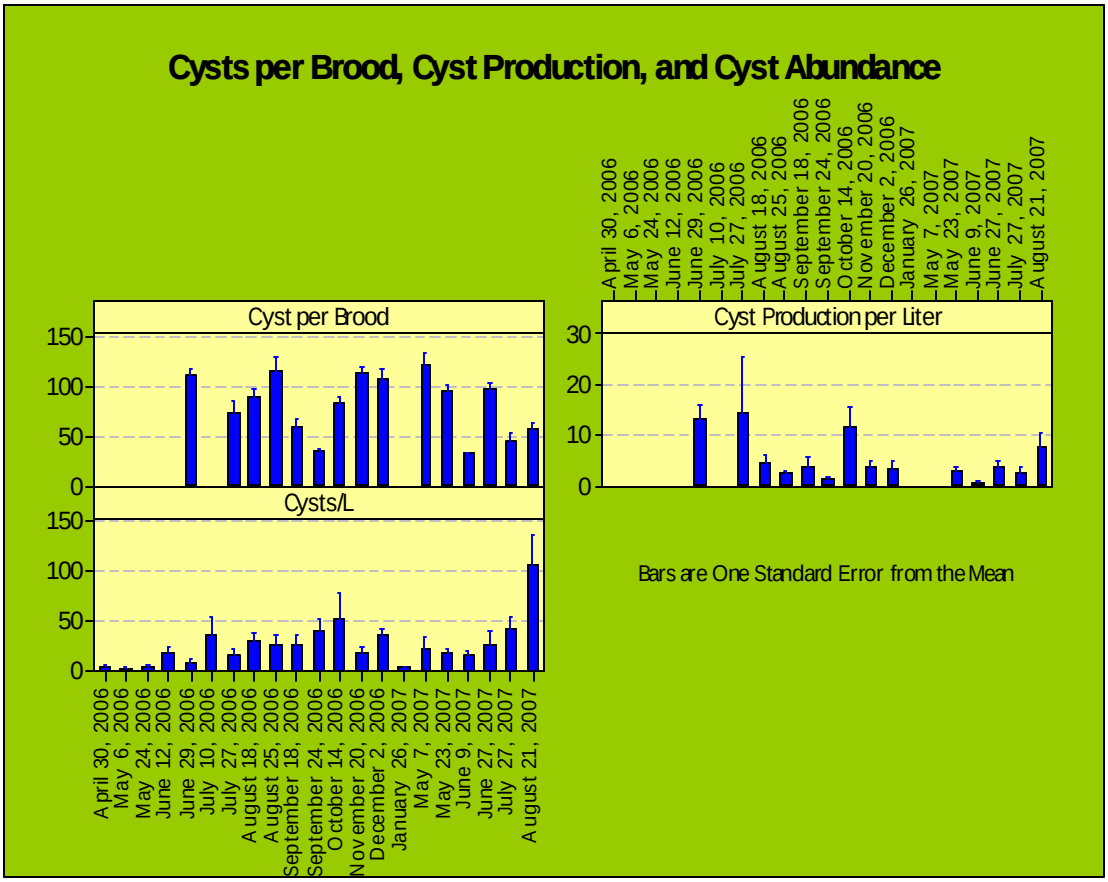
Average cyst abundance on the GSL is the critical parameter used to regulate the brine shrimp industry and to predict the annual harvest yield. It is also the most influential determinant of the amount of floating or shoreline brine shrimp cyst accumulations on the GSL during the winter months. These cyst accumulations are widely exploited as a food source by overwintering species of water birds, gulls, and shorebirds (Figure 22).

Figure 22. Brine shrimp cyst accumulation on the surface of the GSL. Accumulations can be a diffuse monolayer or can accumulate to a thickness exceeding 3 cm. Floating brine shrimp cyst and biomass accumulations are extensively utilized by foraging birds.

Peak cyst abundance during 2006 was observed on October 14 and showed a density of 52.9 cysts per liter (Figure 23 and Appendix 5.1). The lowest measure of cyst abundance during 2006 was on May 6, when 3.2 cysts/L were counted. The range of cysts per liter

during 2007 was from 4.0 (January 26) to 22.3 (May 7). Cyst abundance within the GSL can be patchy in distribution, rendering the arithmetic mean a less accurate measure of central tendency of cyst abundance. Median cyst abundance has been used by previous investigators as the most accurate representation of cyst abundance (Stephens, 1997). Median cyst abundance showed a generally lower value than the mean, especially in terms of peak values; the highest median value was 36.0 cysts/L on December 2, 2006. The highest median measure before the harvest season was 24.1 cysts/L in August. In the following sections the arithmetic mean will be considered because it is the statistic used by the State of Utah, Department of Natural Resources, Division of Wildlife Resources (DWR) to regulate the industry, thereby allowing for direct comparisons of the DWR results with our study.

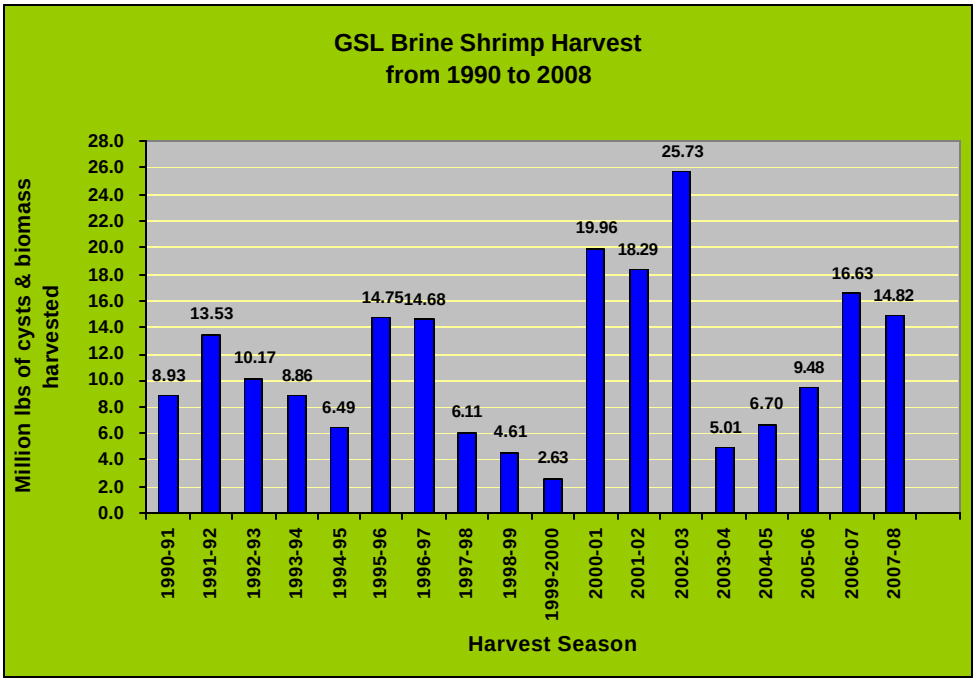
Figure 23. Cyst production by *Artemia* and cyst abundance within the GSL are shown. The dominant shift to oviparity occurred in June and exhibited a triphasic pattern. Cyst production resulted in a steady increase in cyst abundance from June until the onset of commercial harvesting in October 2006.



Because commercial harvesting had already begun on October 1, the estimate of maximal cyst production on the GSL is artificially low. Although cyst abundance was lower, by approximately three-fold, than some of the previous years on the GSL, the brine shrimp industry harvesting total was relatively high. During 2001 to 2005, peak cyst abundance on the GSL ranged from 87 to 158 cysts per liter just before the brine shrimp harvest season, and during that time period the industry harvested 5.0 to 25.7 million pounds per season. This season the brine shrimp industry harvested a total of 16.6 million pounds of

raw biomass from the GSL from October 1, 2006, to January 31, 2007 (Figure 24). By comparison, in 2003 the peak preseason average cyst abundance was 86 cysts/L (median = 72 cysts/L), but the industry harvested only 5 million pounds of raw biomass. The harvest yield for this season may be partially attributable to increased effort during the 2006-2007 harvesting season relative to previous years. Based on our measures of population dynamics, per-capita productivity, and harvest yield for the brine shrimp industry there is no indication that the *Artemia* population is substantially threatened by current conditions on the GSL, whether the concern is contaminants (e.g., mercury, zinc, copper, selenium, hydrocarbons), food availability, abiotic characteristics, predation, or other influential factors.

Figure 24. Raw *Artemia* biomass harvested from the Great Salt Lake from 1990 to 2008. Values are reported in million-pound increments.



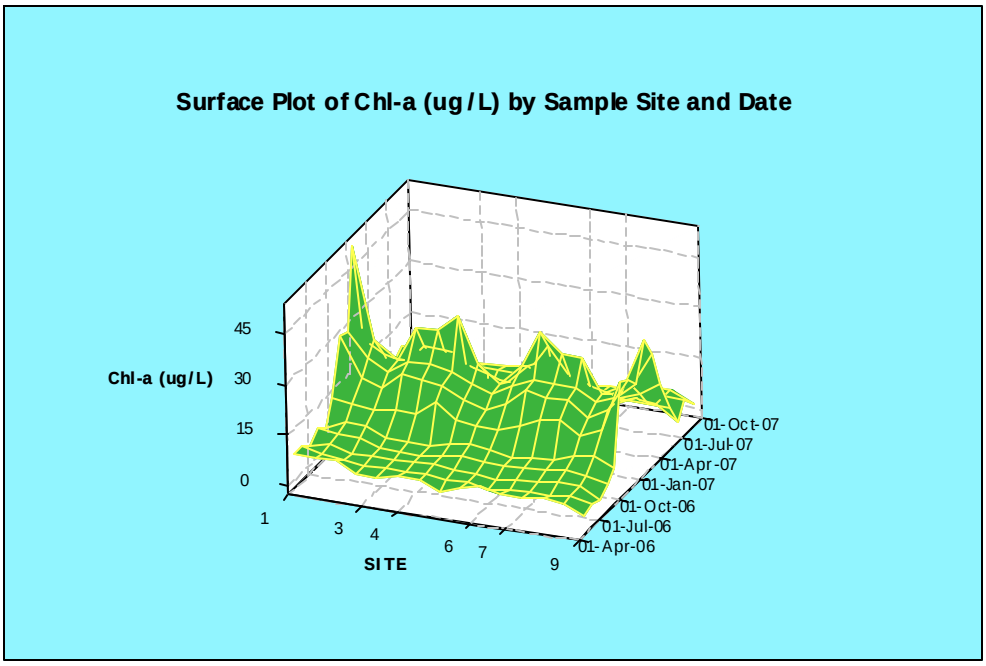
Phytoplankton, Chlorophyll, and Water Transparency.

Water samples were collected during each sampling program and were used to assess chlorophyll pigment concentrations as well as for algae identification and enumeration. Water samples were analyzed for chlorophyll-a and phaeophytin pigments. Average chlorophyll-a levels during 2006 were in the range of 1.9 ug Se/L (September 18) to 30.3 ug Se/L (December 2) (Appendix 7.1). Chlorophyll-a levels during the spring-summer season from April 30 to August 25 2006 did not exceed 7.2 ug Se/L. However, site-specific levels did show a range of 0.7 ug Se/L to16.0 ug Se/L over this same time period. It is likely that throughout the spring and summer the *Artemia* population exerted substantial grazing pressure on the algal food supply and kept chlorophyll levels low. For example, coinciding with decreased grazing pressure in the fall of 2006 (*Artemia* population size reduced to 1.7 individuals/L) the phytoplankton responded with rapid growth and concomitant increases in chlorophyll-a pigments (an average value of 20.8 ug Se/L and a high of 32.0 ug Se/L on October 14) and decreases in transparency—on October 14, 2006, the greatest visible depth was 100 cm with an average of 65.5 cm. This is in contrast to the maximum water transparency in September, which was 460 cm, with an average of 260 cm (Figure 8 and Appendix 7.4).

During the winter of 2007, when grazing pressure on the phytoplankton by *Artemia* was reduced to zero, the algal community responded with abundant growth. Mean chlorophyll-a concentration increased to 41.7 ug Se/L, and a high of 51.0 ug Se/L, in January. By March 15 the average concentration had decreased to 33.7 ug Se/L. Following the onset of hatching and the recolonization of *Artemia* in April, the

concentration of chlorophyll-a had decreased to7.5 ug Se/L. Subsequent sampling programs on May 23 and June 9 showed similar, albeit lower, chlorophyll-a levels to those observed during the spring and early summer of 2006. The concentrations were 1.8 ug Se/L on May 23 and 1.7 ug Se/L on June 9, 2007. Figure 25 portrays the chlorophyll-a concentration over the entire project period (May 2006 to August 2007) and by sample site.

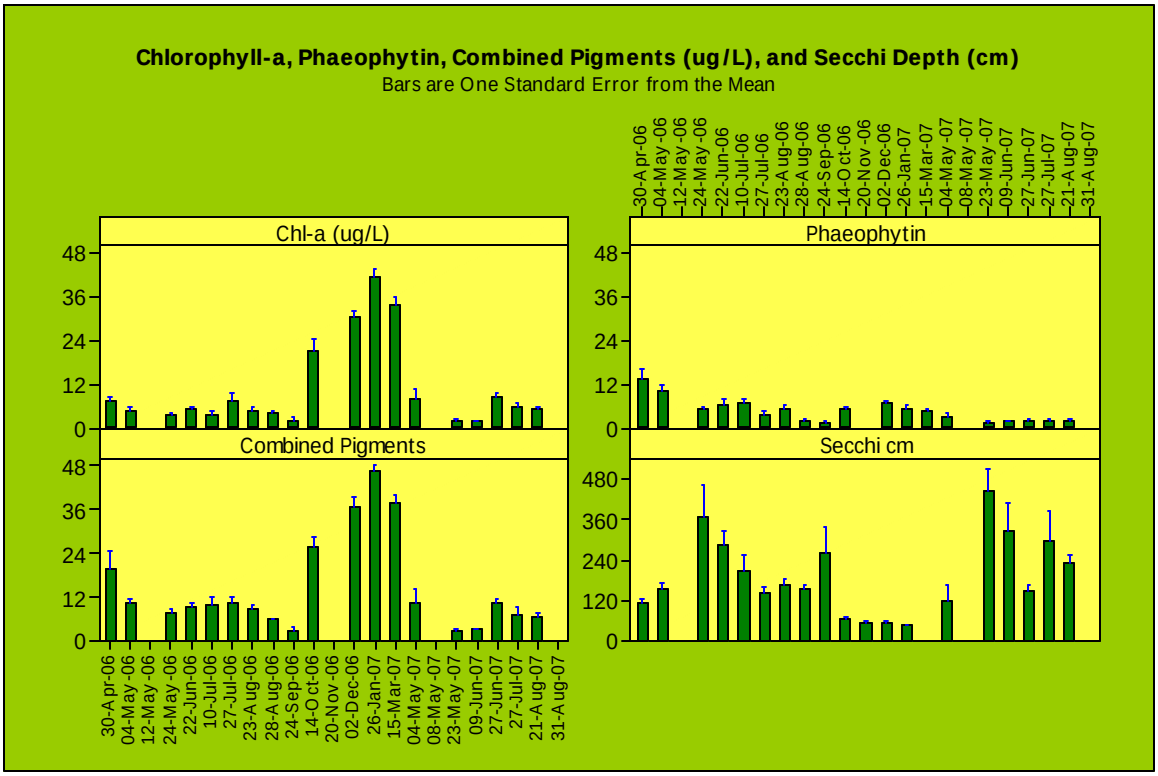
Figure 25. Surface plot of chlorophyll-a from May 2006 to August 2007. The temporal and spatial aspects of chloropyll-a can be observed. Grazing pressure from the brine shrimp population maintains the chlorophll-a production to below 10 ug Se/L throughout the Spring, Summer, and early Fall. Once the grazing pressure diminishes, algal population growth increases substantially and chlorophyll-a concentrations in the water correspondingly increase.



There were substantial differences in phaeophytin concentration between the spring of 2006 and 2007 (Appendix 7.2). In 2006 the phaeophytin concentration was highest on April 30 (13.1 ug Se/L) (Figure 26). The concentration decreased steadily thereafter and

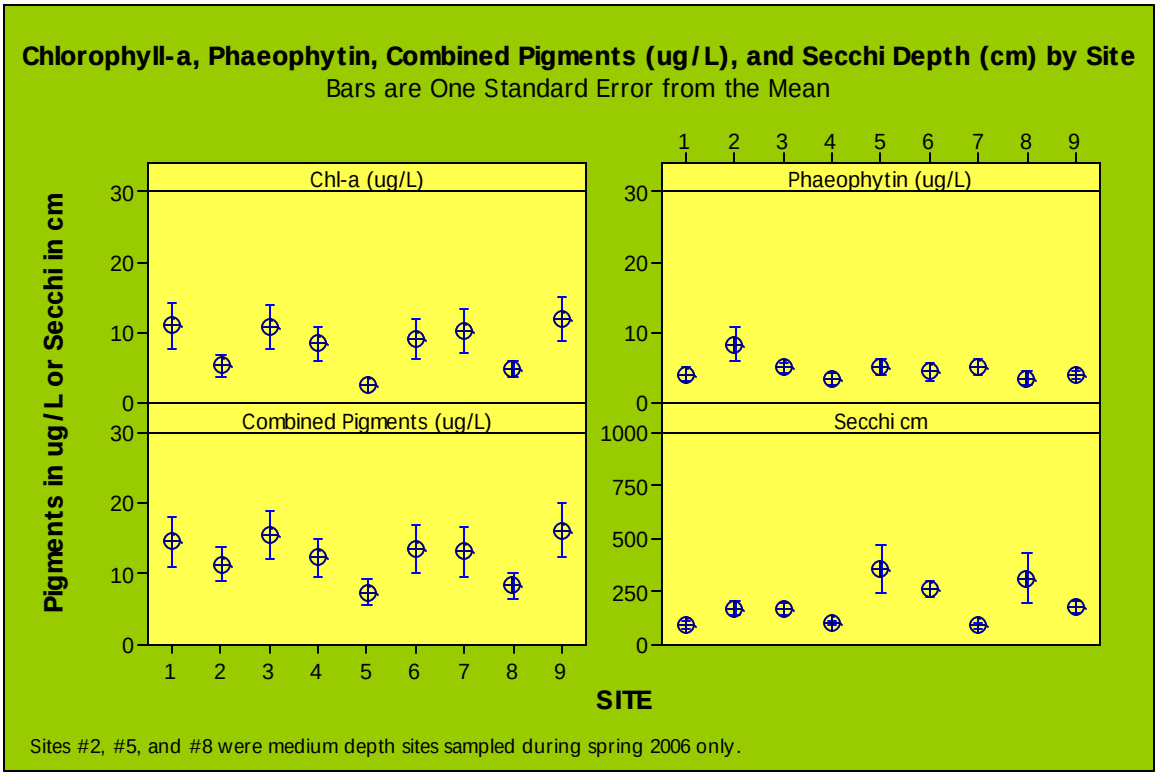
was in the range of 1.2 to 6.5 ug Se/L for the remainder of 2006. In contrast, phaeophytin levels during 2007 have not exceeded 6.5 ug Se/L and steadily decreased from this level in December to a low of 1.2 ug Se/L on May 23.

Figure 26. Interval plots in ug Se/L for chlorophyll-a, phaeophytin, and combined pigments (phaeophytin & chlorophyll-a) and Secchi depth (cm) for GSL water samples collected from April 2006 to June 2007.



A comparison of average chlorophyll concentration by site is a useful indirect measure of differences that may exist spatially in algal production. Figure 27 shows mean values and 95% confidence intervals for chlorophyll-a, phaeophytin, combined pigments and Secchi depth by sample location.

Figure 27. Site-specific interval plots in ug Se/L for chlorophyll-a, phaeophytin, and combined pigments (phaeophytin & chlorophyll-a) and Secchi depth (cm) for GSL water samples from April 2006 to June 2007.

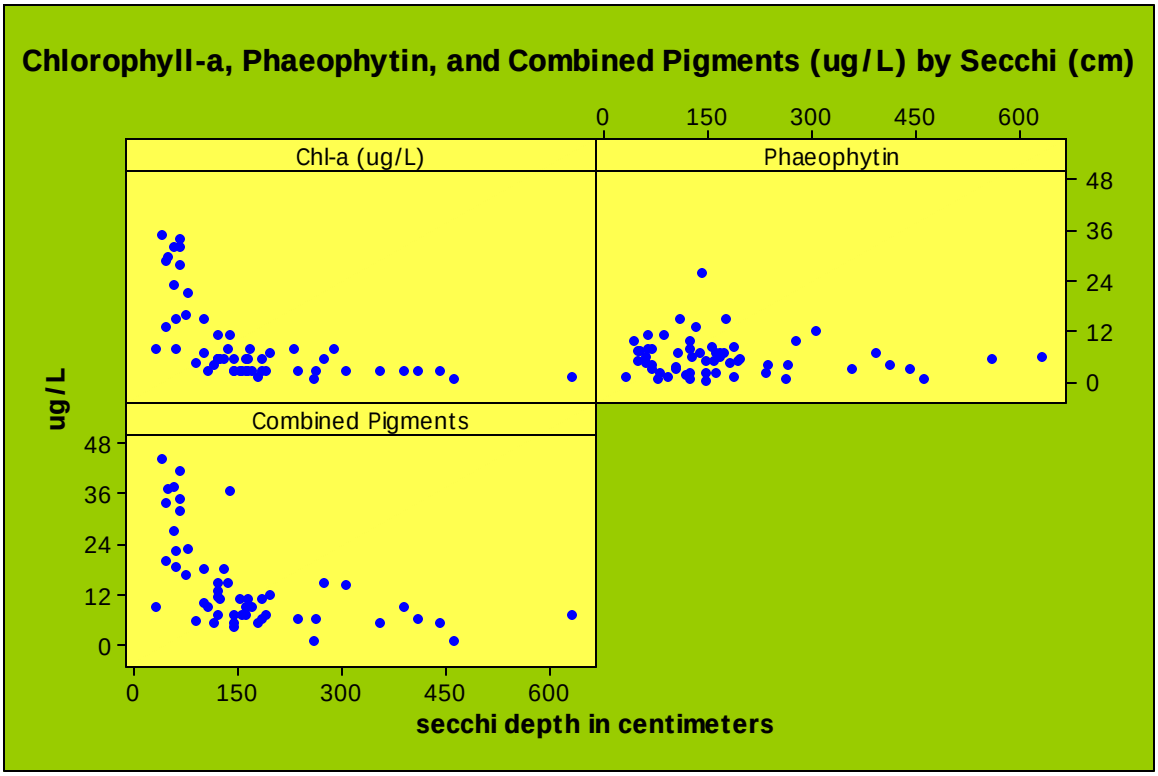


The results for sites 2, 5, and 8 (medium depth) are generally lower than the other sites. This is understandable in the context of the sampling schedule—medium-depth sites were included in the study only during the spring and early summer of 2006. During this time period grazing pressure on the algae remained high and did not allow for substantial algal growth. The maximum values of chlorophyll-a for all deep and shallow sites, except site #1 (Fremont Island), were quite similar and ranged from 37 to 43 ug Se/L. Site #1 did have a higher peak value of 51 ug Se/L, suggesting that this location may have greater primary productivity than the other locations. It is noteworthy that this location is near

fresh water inputs from the Bear River, Ogden Bay, and Farmington Bay. Medium depth sites had much larger 95% confidence intervals, which may be attributable to the limited number of samples taken from these sites relative to the deep and shallow sites.

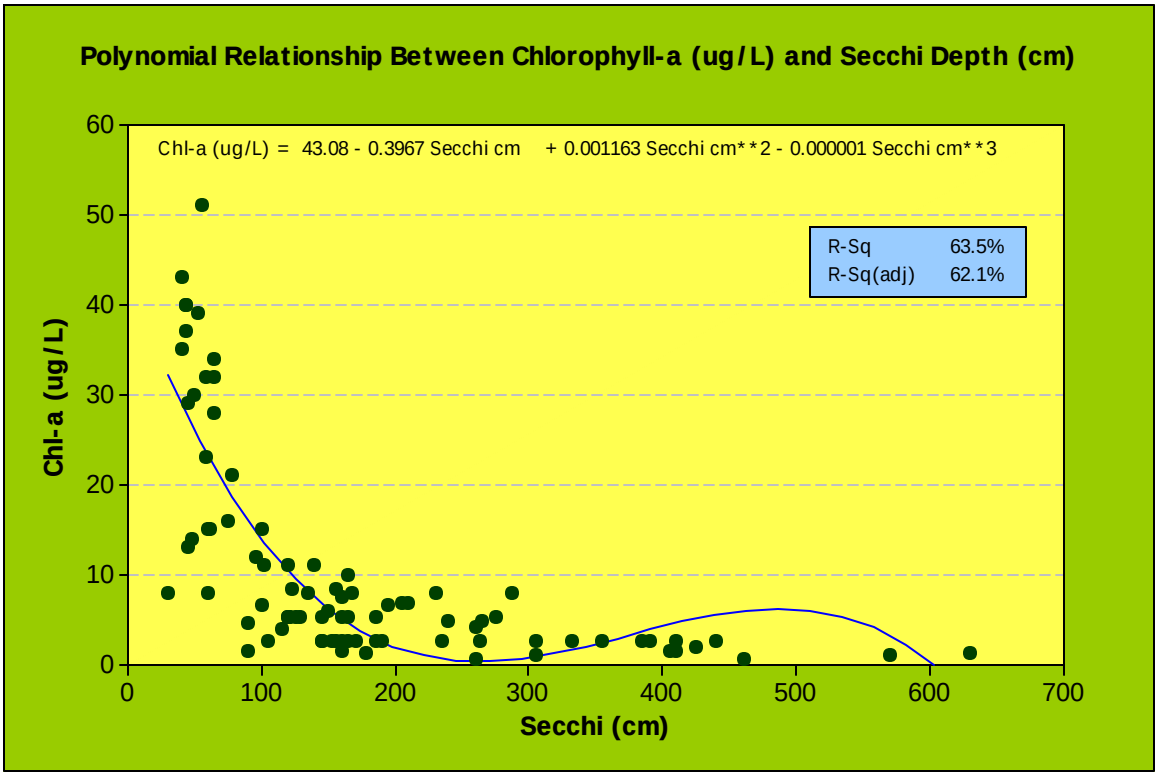
Water transparency measurements can be used as an indirect measure of primary productivity in lakes. The relationship between Secchi depths and chlorophyll-a concentrations is presented in Figure 28. We observed a pattern of exponentially increasing chlorophyll-a concentrations as Secchi depth decreased below 1.5 meters. Similar patterns demonstrating an exponential relationship between low Secchi depth and chlorophyll have been documented in other lake studies (Dodds, 2002). At Secchi depths of $\leq$1 meter chlorophyll-a concentrations were generally between 10 to 50 ug Se/L. Between one meter and three meters transparency the chlorophyll-a values were usually between 3 and 8 ug Se/L. At high levels of water clarity, at least with respect to the GSL, chlorophyll-a levels were very low, typically falling below 3 ug Se/L.

Figure 28. Scatter plot of Secchi depth and algal pigments for the GSL. Samples were collected from April 2006 to June 2007. Results show a characteristic exponential decline in chlorophyll-a as Secchi depth increases. Secchi depths of less than 1.5 meters correspond to levels of chlorophyll-a that are generally associated with robust growth and productivity of *Artemia*.



A best fit line was described for the relationship between chlorophyll-a and Secchi depth Figure 29). A polynomial equation was defined that can be used to estimate chlorophyll-a levels in the GSL when provided with Secchi depth measurements. It must be kept in mind that the accuracy of this equation will be influenced by the relative composition of the phytoplankton population due to differences in amounts of chlorophyll-a produced by the many species of algae found within the GSL. Turbidity, decomposing biomass, and other factors can affect Secchi depth measurements. However, in a chlorophyte-dominated algal population this equation should be a generally useful predictive tool.

Figure 29. The relationship between Secchi depth and chlorophyll-a for GSL water samples is shown and a best-fit line is provided. A reasonably good fit of a cubic polynomial equation (R^2 = 0.627) describes the relationship observed for the GSL during 2006 and 2007. The distribution of chlorophyll measurements may be decidedly different with changes in the relative abundance of phytoplankton taxa.



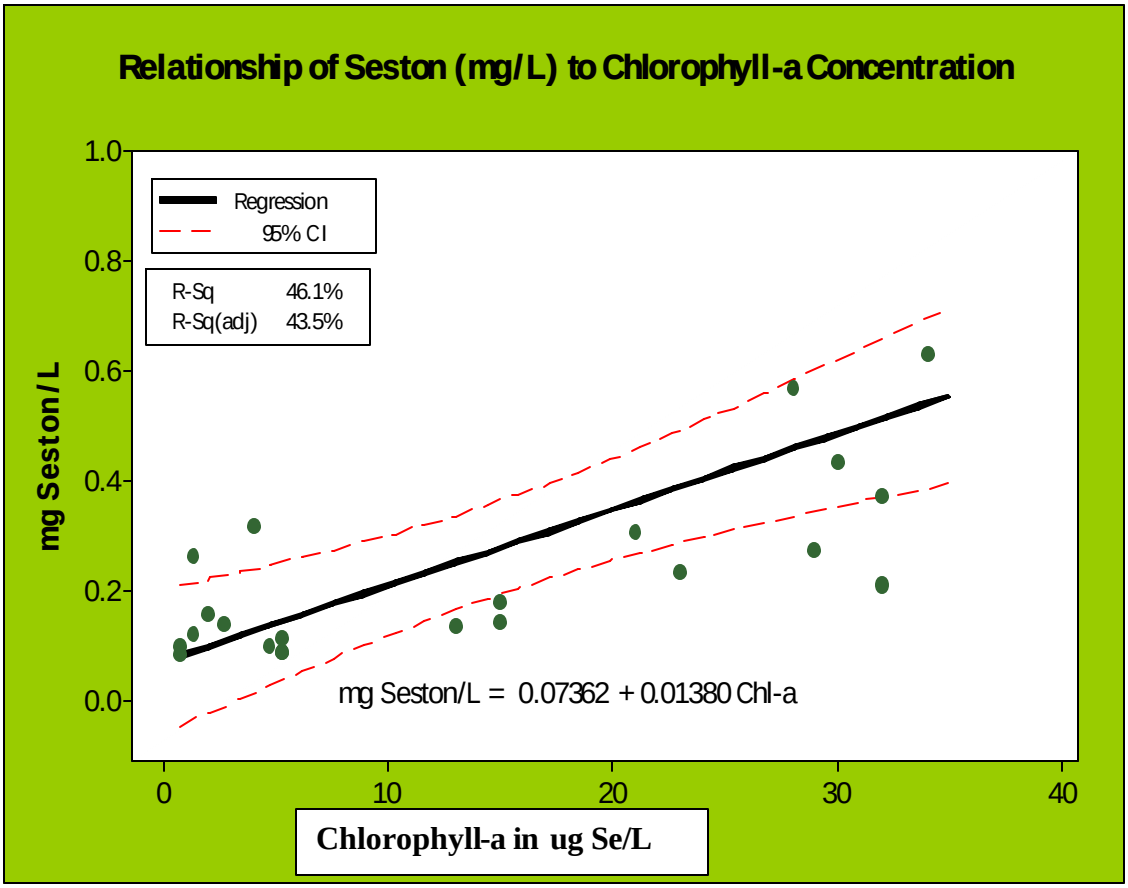
The mean and median chlorophyll-a concentration for all sites and sampling dates were 10.12 and 5.30 ug Se/L respectively. These statistics, and the maximum range over which chlorophyll-a is observed in the GSL, would characterize the GSL as a mesotrophic lake, fluctuating between robust algal growth and transient depletion of phytoplankton due to *Artemia* grazing pressure. As chlorophyll-a levels decline below 5 to 7 ug Se/L on the GSL, food-stress appears to induce a shift to oviparous reproduction. This shift to oviparity occurs at a similar concentration of chlorophyll as indicated in

laboratory studies (Gliwicz, et al., 1995). Other investigators have shown that survival declines dramatically as chlorophyll-a concentrations fall below 5.0 ug Se/L, and especially below 2.5 ug Se/L, (Belovsky and Mellison, 1997). In our study, average chlorophyll-a concentration was below 5.0 ug Se/L during 7 sample programs in 2006 and 2 programs in 2007, in which the ug Se/L. It was less than 2.5 ug Se/L during three sampling programs (Appendix 7.1). Improved accuracy in identifying the critical threshold of chlorophyll that is associated with changes in reproductive modes would require frequent sampling (i.e., weekly) from March to mid-June.

The relationship between chlorophyll concentration and seston yield per liter filtered was examined in the data. This relationship and that of Secchi depth to seston yield have practical applications for this and future studies. It is of value in the design of lake sampling protocols to anticipate seston yield from water filtration. The relationship between an easily measured endpoint (e.g., Secchi depth) or an alternative endpoint (e.g., chlorophyll) and seston yield can assist the investigator in anticipating the volume of filtered water required to provide adequate seston sample size for analytical purposes.

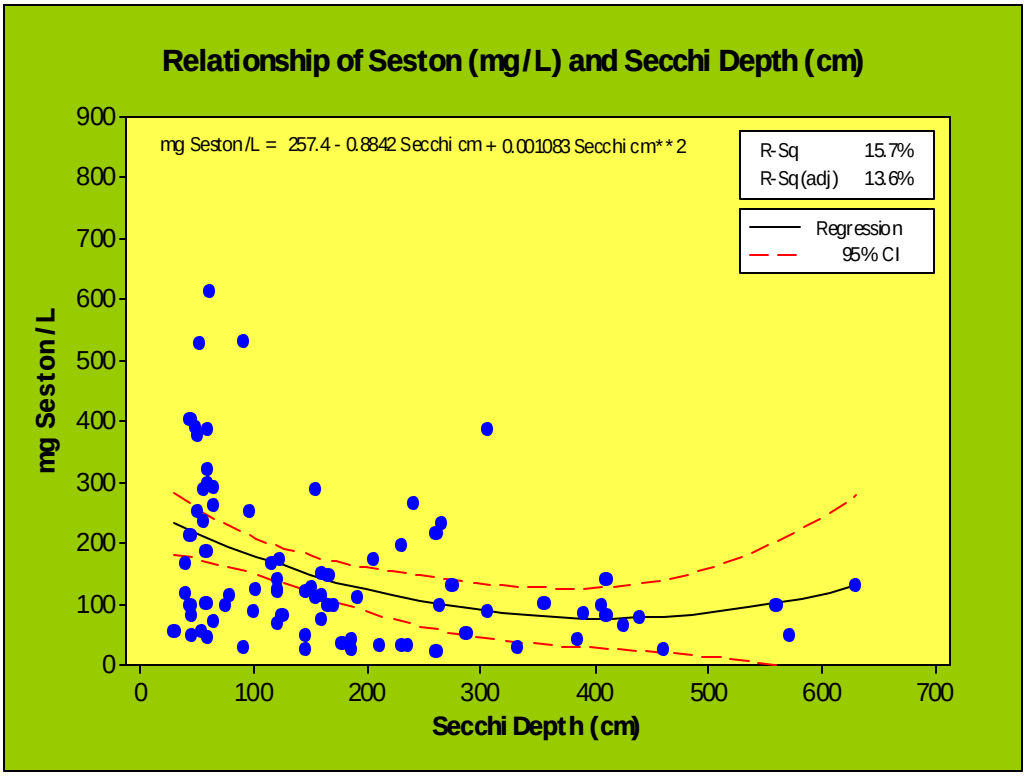
The relationship of chlorophyll and seston yield is shown in Figure 30. There is a moderate positive relationship ($R^2 = 0.461$) between chlorophyll-a and the yield of seston in mg/L.

Figure 30. Relationship of seston yields to chlorophyll-a concentration in GSL water from the same sample location and sampling program. A positive correlation between these two variables was observed.



The correlation between Secchi depth and seston yield was examined toward identifying a relatively easy endpoint to measure that can guide seston sampling protocols. There was a nonlinear negative relationship between seston yield and Secchi depth. A best-fit line relationship is shown in Figure 31. Although the equation provides a range of expected seston yield values, there are obvious limitations to the use of Secchi depth as a predictor of seston yield, especially at the extremes of Secchi depth.

Figure 31. A negative polynomial relationship between seston (mg/L) and Secchi depth can be described for GSL water samples. This relationship has practical applications for estimating the volume of filtered GSL water required for adequate seston sample size. The estimate of volume required can be based on a simple assessment of water transparency.



Seston samples were collected by filtering known volumes of GSL water through 0.45-micron, 142-mm, cellulose acetate filters (flatstock filters). Filtration was initially done (May to July 2006) on equivalent volumes (one liter) of GSL at each sample site. Due to concerns about low yield and limits of detection on seston samples, the volume filtered was increased—filtration was continued until the filters were clogged with particulate matter. The volume of GSL water filtered was then recorded. The cellulose acetate filters used in this study exhibited similar capacities at the point of clogging—the average

weight of material on the filters was 393 mg of seston. The mean quantity of seston per liter was 123.1 mg/L in 2006 and 185.8 mg/L in 2007.

Phytoplankton Composition and Abundance.

Although phytoplankton analysis was not included in the initial project budget, it was deemed important to examine, to the extent possible, the phytoplankton composition over the course of this study. Water samples were pooled according to geographic region (Northeast, Central, Southeast) and preserved in a combination of Lugol's solution (0.5%) and 1% formaldehyde solution. The samples were used for phytoplankton identification and enumeration. The results from May through August 2006 are shown in Figures 32 to 37. Results from subsequent sampling programs are awaiting finalization.

Figure 32. Relative abundance of GSL phytoplankton on May 25, 2006.

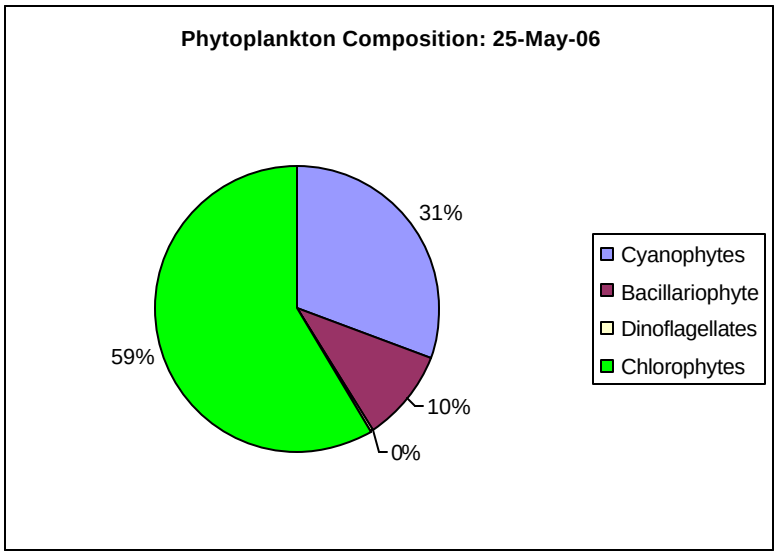


Figure 33. Relative abundance of GSL phytoplankton on June 29, 2006

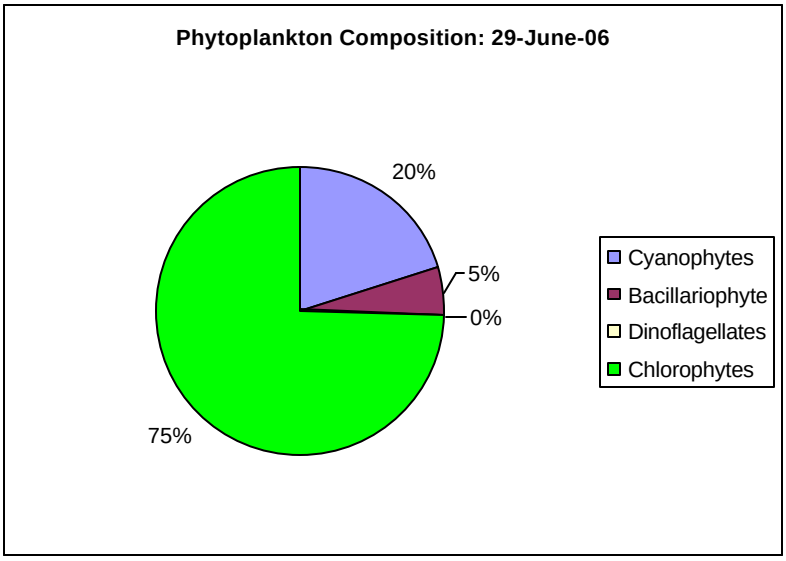


Figure 34. Relative abundance of GSL phytoplankton on July 10, 2006

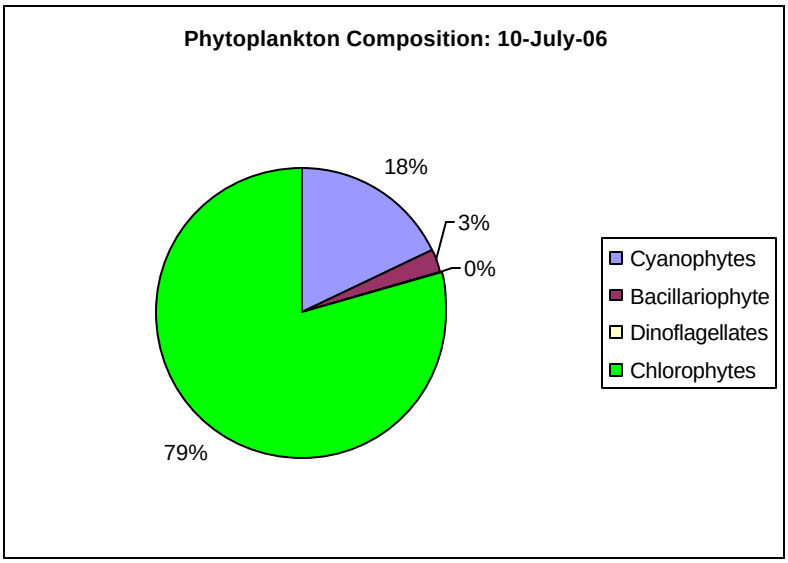


Figure 35. Relative abundance of GSL phytoplankton on July 27, 2006

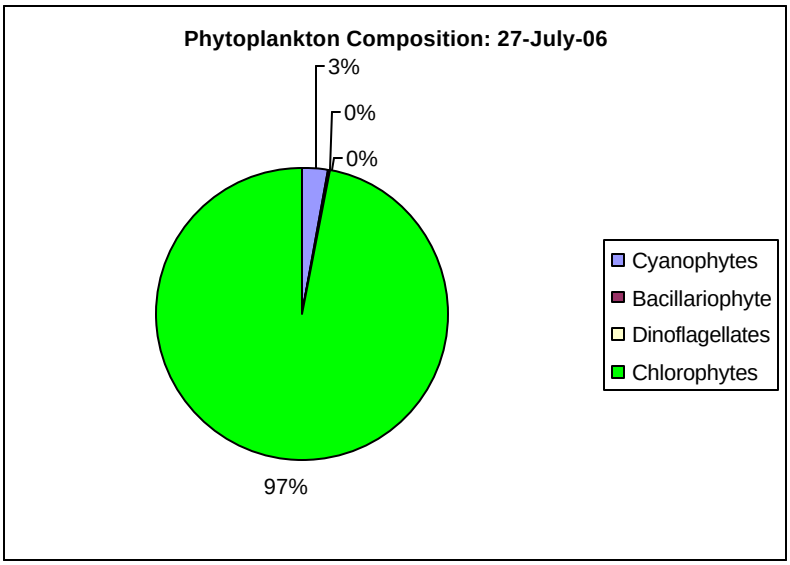


Figure 36. Relative abundance of GSL phytoplankton on August 18, 2006

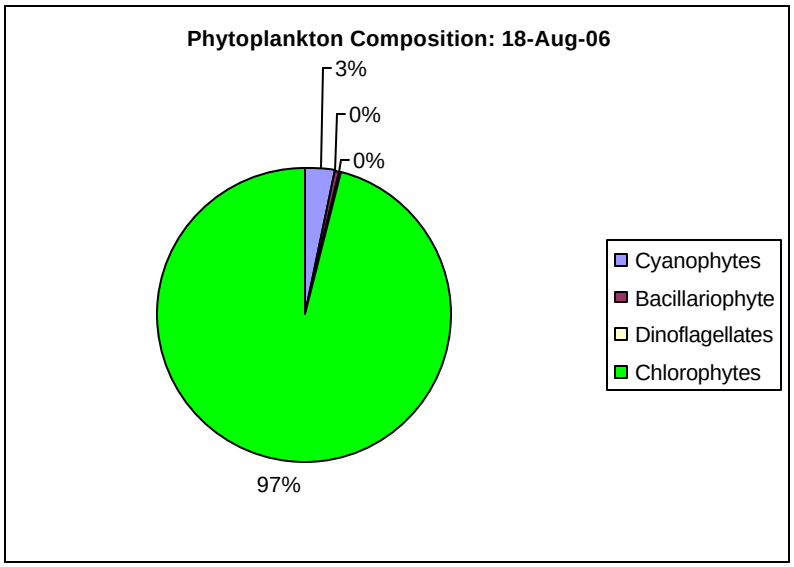
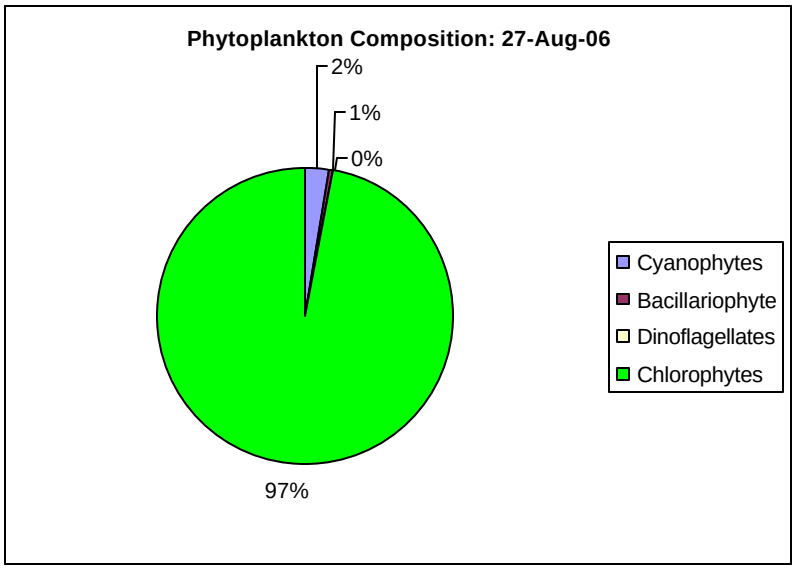


Figure 37. Relative abundance of GSL phytoplankton on August 27, 2006



There was a progressive shift in relative abundance from May to August 2006 in which the relative percentage of chlorophytes increased in dominance reaching a peak relative abundance of 97% in late July and sustaining this level throughout August. The composition of phytoplankton during earlier months exhibited a greater presence of other algae. In May, chlorophytes represented only 59% of the phytoplankton while cyanobacteria (31%) and bacillariophytes (10%) made up the remaining 41%. The combined percentage of cyanobacteria and bacillariophytes decreased to 25% in June and then to 13% in early July. The dominant genus of phytoplankton was *Dunaliella*.

Cell counts were determined in the phytoplankton samples and are shown in Table 8. Cell counts were lowest in June (47,672 cells per liter) and were the highest on July 27 (622,350 cells per liter). These results do not correlate well with chlorophyll measurements—a regression analysis of the relationship between algal cell count and chlorophyll results in a weak positive linear relationship (R^2 value = 0.239). Algal cells are quite fragile and can easily be damaged during prolonged storage or transport and by the filtration/resuspension method of counting used in this study (especially flagellated cells). Ideally, samples should be analyzed within days of collection (Stephens, 1997). It is possible that storage conditions and transport may have had an adverse effect on the algal cells and may have altered the accuracy of cell counts. Notwithstanding these concerns, our results for algal cell counts are similar in range to previous studies (Stephens 1997, 1998, 1999). It is also noteworthy that in these previous studies no clear relationship between chlorophyll, brine shrimp population structure, and algal cell counts was reported.

Table 8. Phytoplankton cell counts from GSL water samples taken from May 2006 to August 2006. Counts are expressed in cells per liter.

Date	Cyanophyceae	Bacillariophyceae	Dinophyceae	Chlorophyceae	Total
May 25, 2006	16,157.66	5,531.26	167.60	30,921.79	52,778.31
June 29, 2006	9,683.43	2,467.41	-	35,521.41	47,672.25
July 10, 2006	27,541.90	4,022.34	111.73	123,156.42	154,832.38
July 27, 2006	17,569.83	1,747.37	-	603,032.24	622,349.45
August 18, 2006	12,247.06	999.39	105.53	341,852.90	355,204.87
August 25, 2006	1,725.63	366.23	-	67,554.30	69,646.17

SELENIUM IN BRINE SHRIMP TISSUE

Selenium analysis results from brine shrimp tissue are presented for each year separately. This format is used for this report because changes were made in the brine shrimp tissue sample preparation methods in 2007 that had a substantial effect on the measured concentration of selenium in brine shrimp tissue. The methods used for the samples collected during 2006 introduced a downward bias in the calculation of selenium on a dry weight brine shrimp tissue basis—residual salt in the samples decreased the apparent concentration of selenium in brine shrimp tissue. Therefore, uncorrected values for all of the 2006 brine shrimp tissue in this report are below true selenium concentration values. Because of this known influence of sample preparation and analytical laboratory procedures on the selenium measurements for the 2006 samples the results are evaluated separately from the 2007 results and the 2006 results should not be used for management purposes.

The methods used to prepare and analyze samples from 2007 were improved and resulted in reliable values that are consistent with previous and concurrent research on selenium in GSL brine shrimp tissue. The results from 2007 therefore can be used for any management decisions and for the purpose of establishing a selenium standard for the GSL. The results from 2006 have been reevaluated using a correction factor that was derived by collecting and preparing co-located samples using the "2006" and "2007" methods. The corrected 2006 values can be used for general comparisons with other data, but are not sufficiently rigorous to be used for regulatory purposes.

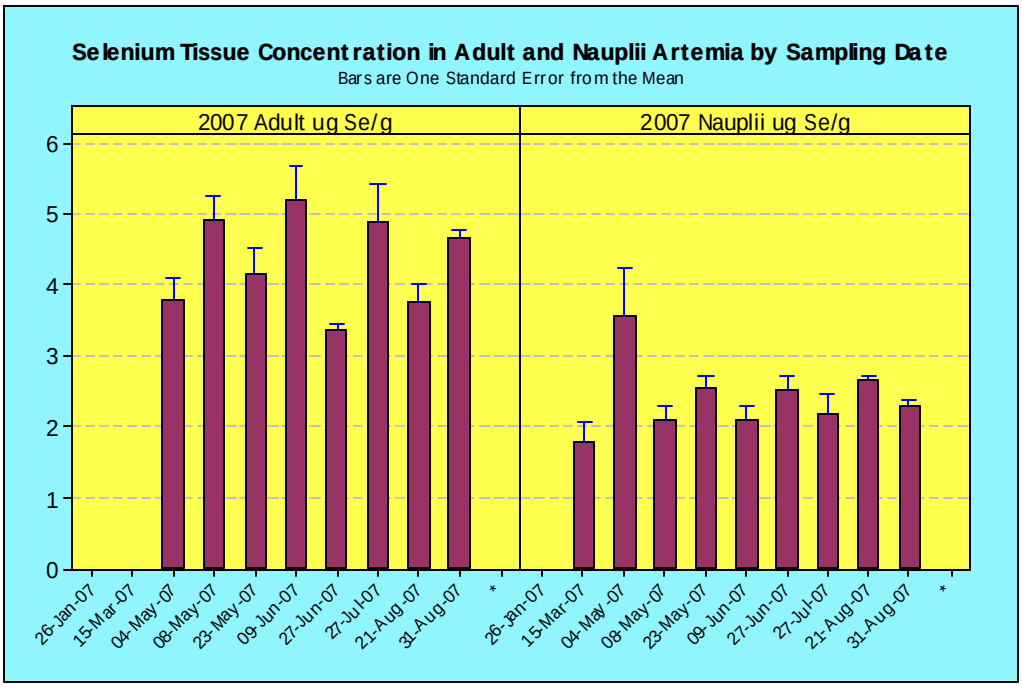
2007 Results: Selenium in Brine Shrimp Tissue

The main modifications made for the sample collection and preparation of brine shrimp tissue during 2007 included increasing the sample size and adding an additional filtration step after age-classes were separated. The final filtration step was used to remove any residual salt, but was done in a manner that maintained the osmolarity of brine shrimp tissues. The same three age-classes (nauplii/cysts, juveniles, and adults) that were collected in 2006 were also included in the 2007 season. All age-classes were submitted for selenium analysis for each sampling program. Although an effort was made to increase sample size during the 2007 season there were still many sampling programs in which the juvenile fraction was insufficient (i.e., < 0.10 g dw) to derive an accurate selenium determination. Because of this limitation the juvenile fraction results will not be presented nor discussed in this section, though the results are included in Appendix

8.2. In contrast, adults and nauplii were collected in sufficient quantities (i.e., > 0.50 g dw) for reliable selenium determination.

The average concentration of selenium in adult brine shrimp tissue during 2007 was 4.32 ug Se/g and the geometric mean for all of the 2007 sampling programs was 4.30 ug Se/g (Figure 38). The lowest average adult tissue value occurred on June 27, 2007 and was 3.37 ug Se/g. The highest average value was 5.21 ug Se/g and was observed on June 9, 2007. The sampling dates and the corresponding selenium tissue values for adult and brine shrimp are shown in Figure 38 and in more detail in Appendix 8.1.

Figure 38. Tissue selenium concentration in brine shrimp adults and nauplii/cysts from 2007. Selenium concentrations are expressed as arithmetic means for each date.



Nauplii and cysts were analyzed for selenium together as one age-class. However, on March 15, 2007 only cysts were collected and analyzed. The selenium tissue value (1.72 ug Se/g) on this date for the nauplii/cyst fraction represents the cyst selenium concentration only. The geometric mean selenium tissue value for the nauplii/cyst fraction for 2007 was 2.35 ug Se/g and the arithmetic mean value was 2.42 ug Se/g. The highest selenium concentration was measured on May 4, 2007 and showed 3.56 ug Se/g while the lowest value of 2.09 ug Se/g occurred on June 9, 2007. The other average daily values were quite consistent and were between 2.18 and 2.65 ug Se/g (Figure 38).

Spatial and temporal differences and trends were analyzed for selenium in brine shrimp tissue using one-way ANOVA. Significant differences among the adult brine shrimp results for the 2007 data set were observed for sampling date, depth characteristics, and geographical region. Although no definitive temporal trend was identified for selenium in adult brine shrimp tissue, comparisons over time showed alternating fluctuating patterns. Whereas the differences among sample dates were significant ($P < 0.000$; 16, 86 DF), these differences are not apparent if results are grouped by month rather than actual sample date ($P=0.640$; 3, 41 DF). The population structure of brine shrimp does vary temporally, and differences are observed on weekly or bi-weekly basis. It is possible that the discrete age structure differences (i.e., age of adults) of the population may have some influence on the apparent selenium tissue concentration for a given location and sample date. Although we analyzed broad groups of age-classes separately, there can be substantial differences among adults in terms of the duration that an adult has been living and foraging in the GSL. It is possible that the amount of time an adult has spent

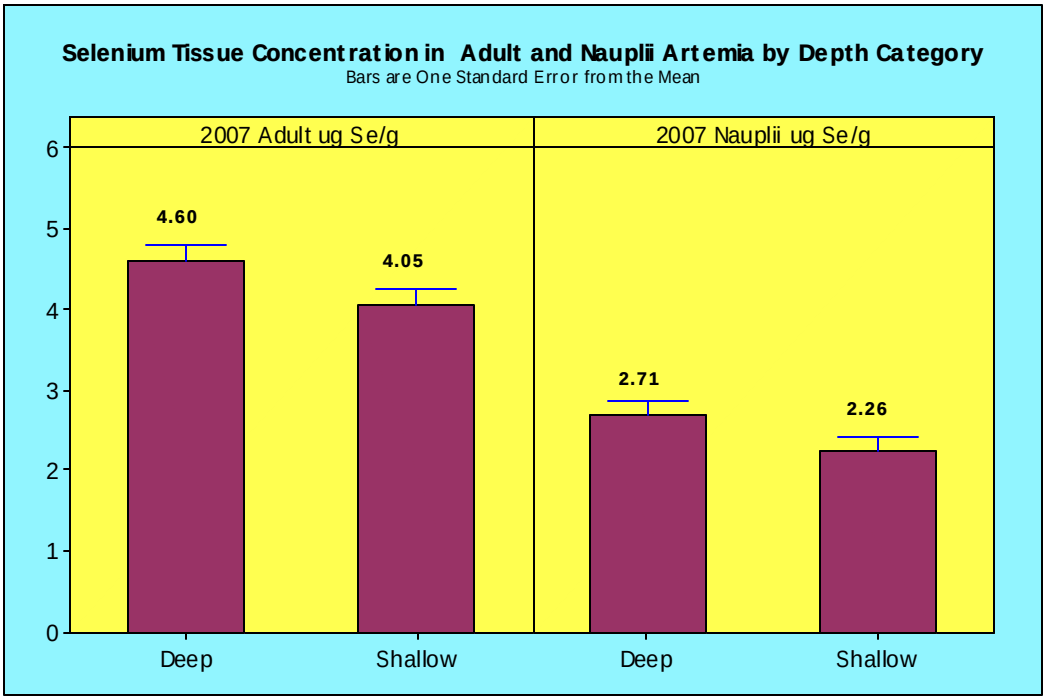
foraging on selenium contaminated algae could have an influence on the individual brine shrimp body burden of selenium. We have demonstrated that this pattern of accumulation exists between age-classes; adults have nearly a two-fold increase in selenium tissue concentration relative to the younger nauplius age-class.

The adult brine shrimp tissue concentration reported for 2007 brine shrimp tissue samples (4.32 ug Se/g) was in close agreement with the few other samples of brine shrimp collected and analyzed by concurrent GSL research teams or in the scientific literature. The average value of selenium in brine shrimp in Conover's (2007) database was 4.5 ug Se/g and of the few samples listed for Cavitt (2007) the values were 2.5 to 3.2 ug Se/g. Our concentration of 4.32 ug Se/g was also somewhat higher than that reported by Brix et al. (2003), who reported selenium tissue concentrations of 2 to 3 ug Se/g for samples collected from the open water of the GSL. Our values are also some higher than those presented by Brooks (2007); she cited studies from 1994 to 2004 that measured 0.3 to 4.5 ug Se/g selenium in brine shrimp. Consistent with studies comparing brine shrimp to brine flies, the selenium concentration in brine shrimp tissue in the current study was higher than concentrations reported by Cavitt (2007) for brine fly larvae (0.8 to 3.8 ug Se/g) and those reported for brine fly larvae (1.3 ug Se/g) and pupae (1.8 ug Se/g) by Wurtsbaugh (2007).

Selenium values in brine shrimp adult tissue were grouped according to spatial and depth categories. The average selenium tissue concentration for adult brine shrimp by depth category is shown in Figure 39. Adult brine shrimp collected at deep sites (>7m depth)

had significantly (P=0.050; 1, 43 DF) elevated selenium tissue concentration compared to samples collected from shallow (1-3m) sites. The mean concentration of selenium in adults from deep sites was 4.60 ug Se/g dw compared to 4.05 ug Se/g dw for shallow sites (Figure 39). Notwithstanding the problems associated with the 2006 brine shrimp tissue selenium values, there was a similar pattern of deep sites showing a slightly higher tissue concentration of selenium than that observed in brine shrimp from shallow sites.

Figure 39. Tissue selenium concentration in brine shrimp adults and nauplii/cysts from 2007. Selenium concentrations are expressed as arithmetic means for each site depth characteristic. Shallow sites showed consistently lower brine shrimp tissue concentrations than were observed at deeper sites.

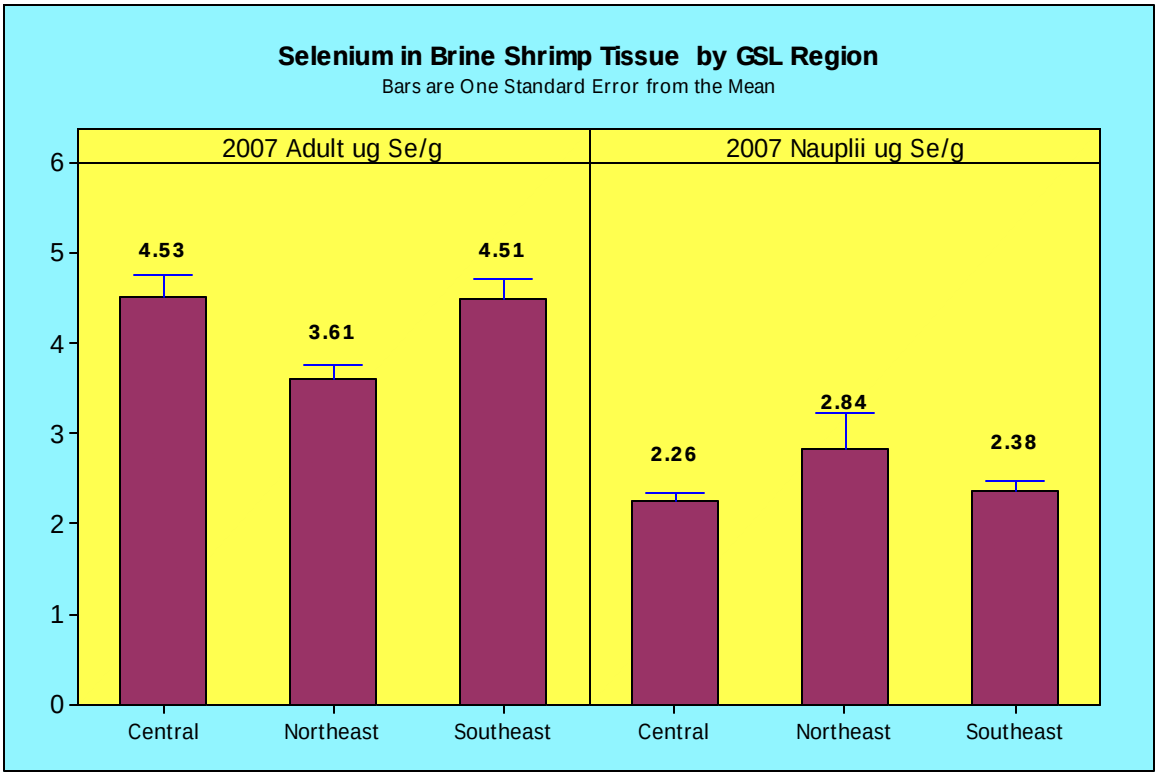


This outcome is of interest with respect to the age structure of the brine shrimp population in a given location and date. Our population results have demonstrated that shallow sites are more productive than deep sites. Shallow sites consistently have higher

dissolved oxygen content, brine shrimp biomass production, and brine shrimp abundance compared to deep sites. This continual production and support of the brine shrimp population could contribute to the observed selenium concentration in brine shrimp tissue indirectly through age structure differences. Laboratory studies of specific ages of brine shrimp and their respective uptake and body burdens would be necessary to confirm this hypothesis. The investigations by Grossell (2007) indicate accumulation of selenium in adults relative to dietary and water concentrations over time, but they don't specifically address the influence of age-structure on tissue selenium assessments.

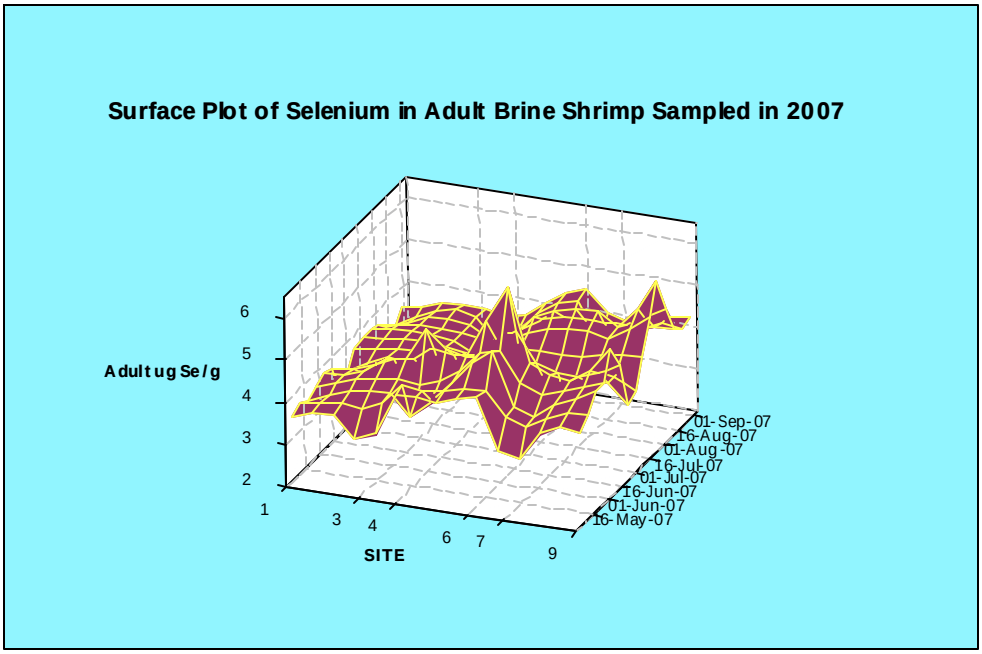
Selenium in brine shrimp tissue was also examined on the basis of geographic region of the GSL. The average values for selenium in brine shrimp tissue, according to region of the GSL, are shown in Figure 40. There were significant differences (P=0.026; 2, 42 DF) in selenium tissue concentration among the three regions of the GSL for adult brine shrimp, but no significant differences were observed for the nauplii/cyst fraction. The region designated "Northeast" includes samples sites that are influenced by input from Ogden Bay, Farmington Bay, and Willard Bay. The phytoplankton composition, water characteristics, and abiotic factors do differ in this region from other regions of the GSL that are further removed to the west and south. However, the results for brine shrimp tissue concentration do not correspond to differences in selenium from unfiltered water—there were no differences among regions in the concentration of selenium in unfiltered water samples (Figure 40). The differences in this region may simply be an artifact of inherent population differences, sampling frequency and sample size.

Figure 40. Tissue selenium concentration in brine shrimp adults and nauplii/cysts from 2007. Selenium concentrations are expressed as arithmetic means for region.



The combined spatial and temporal patterns of selenium in brine shrimp are displayed in Figures 41 and 42. Although these surface plots can be difficult to interpret, they do allow for an inspection of the pattern of selenium in brine shrimp tissue over time and sample site.

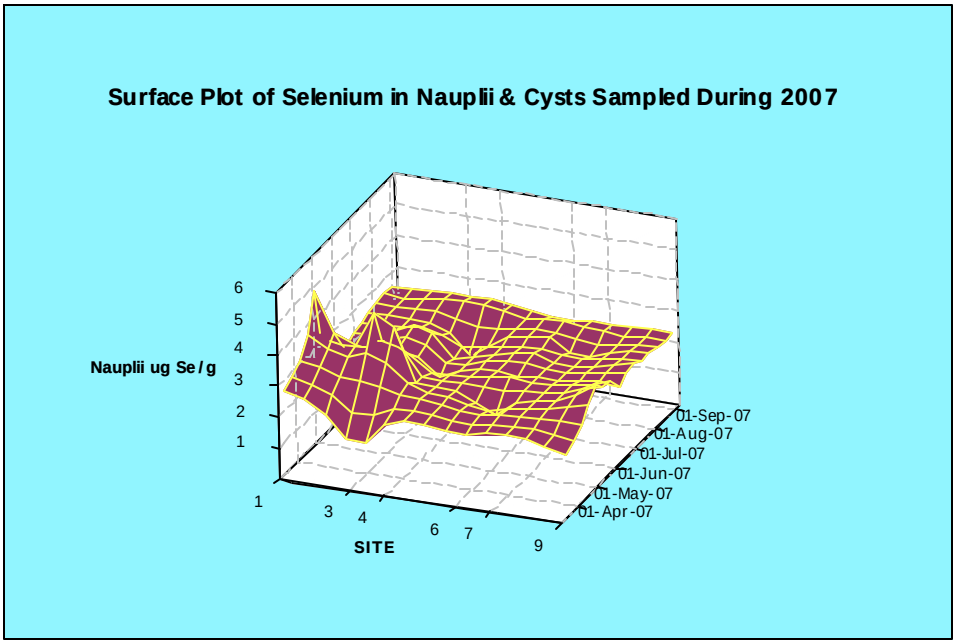
Figure 41. Surface plot of selenium concentration in adult brine shrimp tissue from May to August 2007. The temporal and spatial aspects of selenium in brine shrimp tissue can be observed.



Separately, the adults were nearly twice the selenium tissue concentration as the nauplii tissue concentration. Regression analysis of selenium brine shrimp tissue from 2007 samples shows a 0.538 coefficient factor for the nauplii tissue selenium concentration relative to the value for adults. The larval stages that were grouped in the nauplius age-class include some early instar stages in which the nauplius is primarily deriving energy from the metabolism of stored lipids. During older stages the stored lipids become depleted and meta-nauplii begin to actively forage for algae. The concentration of selenium in nauplii is slightly higher than the baseline value for selenium in the brine shrimp cysts (1.77 ug/g) observed during the late winter (March 15, 2007), suggesting some uptake of selenium by larval stages (Figure 38).

The results for the younger nauplii age-class are remarkably consistent over time and location, with some exceptions in May 2007-- higher values at sample sites 1 and 3 were observed. It is not clear why these locations exhibited average values well in excess of other locations or sample dates, though it may have been an artifact of sample size.

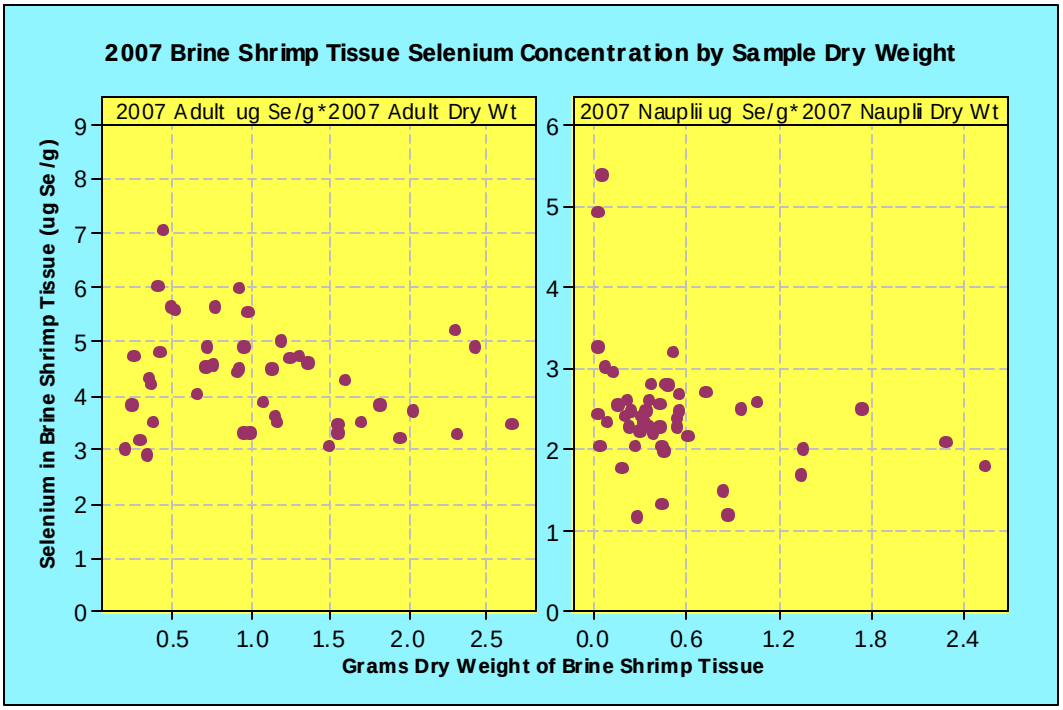
Figure 42. Surface plot of selenium concentration in nauplii/cyst tissue from May to August 2007. The temporal and spatial aspects of selenium in brine shrimp tissue can be observed.



The samples taken during May were some of the smallest yields for the nauplii/cyst fraction over the entire course of the 2007 sampling season—the May 4, 2007 samples had an average weight of 0.053 g dw whereas the average for all nauplii/cysts collected during the 2007 season was 0.573 g dw. The results from selenium analysis for all brine shrimp tissue suggest that limited tissue mass, especially for samples that were less than

0.50 g dw, increased variability in the calculated selenium tissue concentration (Figure 43).

Figure 43. Tissue selenium concentration in brine shrimp adults and nauplii as a function of sample dry weight.



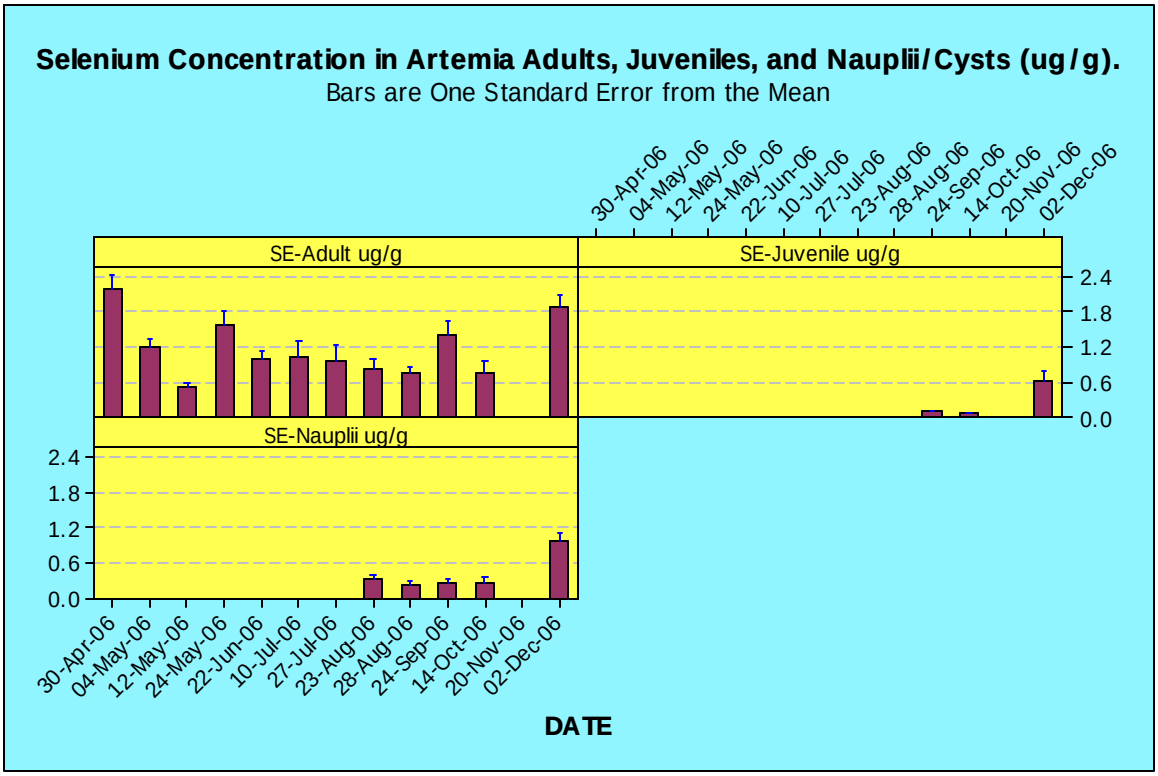
2006 Results: Selenium in Brine Shrimp Tissue

The results for selenium analysis in brine shrimp tissue collected and analyzed during 2006 are presented in this report, as they were in the 2006 draft report. Since the completion of that report the cause of artificially lower values for selenium in the brine shrimp tissue samples was identified. Because of the recognition of artificially low values in the 2006 data set most statistical tests and discussion points have been removed. A correction factor for the 2006 brine shrimp tissue was derived by concurrently sampling, preparing and analyzing brine shrimp tissue using the 2006 methods and

updated “2007” methods. The corrected data were used for some limited statistical analyses.

The results for each sample date are depicted in Figure 44 and are provided in greater detail in Appendices 8.1 to 8.5. The arithmetic mean concentration in adult brine shrimp from April 30, 2006 to December 2, 2006 was 1.185 ug Se/g and the geometric mean was 0.984 ug Se/g. The highest concentration in a single composite of adult brine shrimp was 3.30 ug Se/g. Average concentrations varied across sampling program dates. The highest average concentration of selenium in adult brine shrimp tissue was recorded on April 30, 2006 (2.19 ug Se/g). The lowest average concentration of 0.50 ug Se/g was observed on May 12, 2006. Tissue selenium concentrations in adult brine shrimp were transformed (Johnson transformation—essentially a natural log transformation) and then analyzed by sample date using one-way ANOVA. Selenium concentrations did vary significantly over time ($P < 0.01$, df: 11, 68).

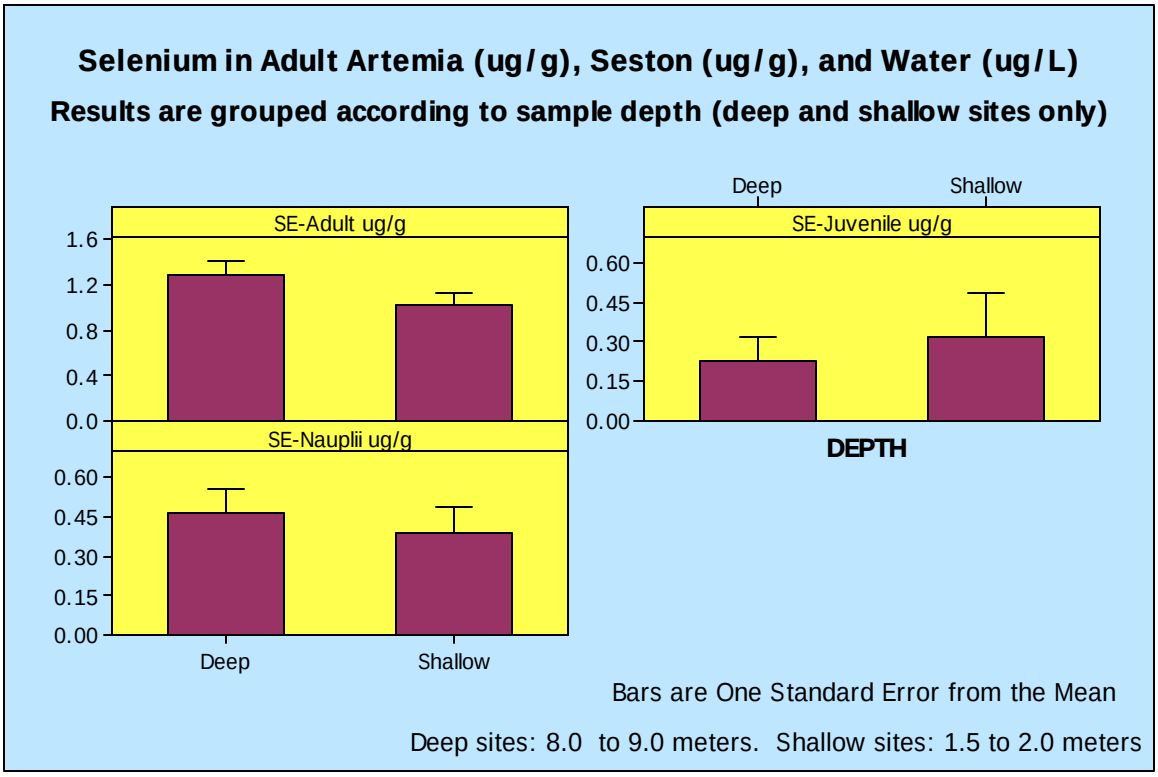
Figure 44. Tissue selenium concentration in brine shrimp adults, juveniles, and nauplii/cysts from 2006. Samples were collected for all age-classes on each sample date. A limited number of the younger age-classes have been analyzed. Selenium concentrations are expressed as arithmetic means for each sample location on a given date.



Tissue concentrations of selenium were quite similar when grouped by type of sample site (i.e., shallow or deep) across regions (Figure 45). Statistical analyses for geographic distribution were done according to regional sample locations (Northeast, Central, Southeast), rather than for site-specific results. No significant differences were found in selenium concentrations across sample locations ($P = 0.759$, df: 2, 77). Grouping brine shrimp tissue concentrations according to depth categories was of interest for this study because of the distinct differences in biogeochemical processes that occur among sites

with distinctly different maximum depths. Since medium depth sites were not sampled throughout the study period statistical tests by depth included only the shallow and deep sites. Although the average concentration of selenium in brine shrimp tissue collected at deep sites was slightly higher (+ 0.28 ug Se/g) than the average for shallow sites, the difference in mean values between these depth categories was not statistically different at the $P \leq 0.05$ level (P=0.085, df: 1, 66).

Figure 45. Selenium concentration in brine shrimp tissue (ug Se/g) grouped according to sample depth. The average concentration in adult brine shrimp tissue for the deep sites was greater than the selenium tissue concentration for the corresponding shallow site in each region of the GSL.

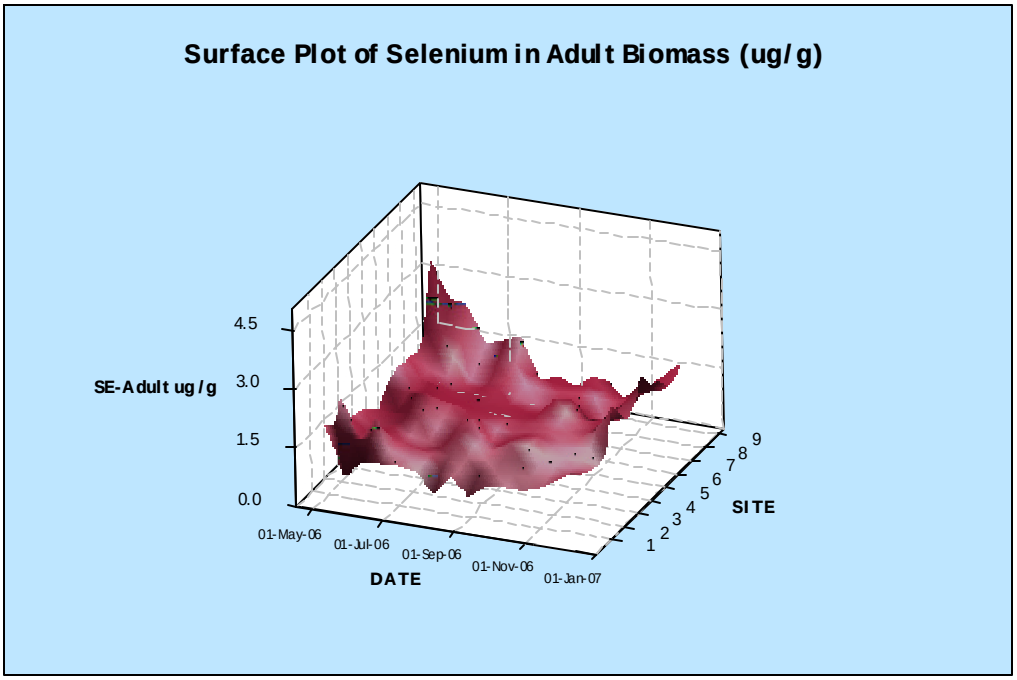


A plot of selenium in adult brine shrimp tissue depicted spatially and temporally is shown in Figure 46. This surface plot provides a constructive visual representation of the

pattern of selenium in brine shrimp tissue. Site #9 (deep site in Southeastern region of the lake) had the highest value observed (3.3 ug Se/g) and was ranked second in average selenium concentration (1.49 ug Se/g). Site #7 (shallow site near the southern end of Antelope Island) had the lowest mean value (0.885 ug Se/g). Temporally, April (2.11 ug Se/g) and December (1.80 ug Se/g) showed the highest mean concentrations of selenium in adult brine shrimp.

As mentioned previously, with regard to evaluating spatial differences in brine shrimp population dynamics and reproductive output, one must always consider that grouping and analyzing results spatially runs the risk of making the incorrect assumption that brine shrimp sampled at given location have been in that particular location sufficiently long to be influenced physiologically or biologically by local biotic and abiotic conditions. We cannot say with certainty that this is the case for the brine shrimp collected in each specific location—we can only examine the results in terms of consistent or meaningful spatial patterns.

Figure 46. Surface plot of selenium concentration in adult brine shrimp tissue from April to December 2006. The temporal and spatial aspects of selenium in brine shrimp tissue can be observed. Although significant differences did exist over time no such differences were found among the geographic locations.



Although juvenile and nauplii/cyst fractions were collected and stored for each sampling program, not all of the samples were analyzed. This was done because the primary focus of this study is in regard to avian dietary exposure to selenium via the food web, and adults comprise most of the *Artemia* biomass as well as the diets of birds foraging on brine shrimp. Therefore, it was determined that all adults would be analyzed and that younger age-class *Artemia* would be analyzed from a subset of the sampling programs (August 2006 through June 2007).

The results for the younger age-classes indicate that there is an age-related difference in the tissue concentration of selenium. Juveniles were 6% to 32% and the nauplii/cyst fraction was 18% to 54% of the selenium concentration in adults for the same sample site and date (Appendices 8.1 and 8.2). Average juvenile tissue selenium levels were quite low with values of 0.06 to 0.61 ug Se/g tissue dry weight and for the nauplii/cyst fraction the selenium concentration was 0.24 to 1.01 ug Se/g. The maximum tissue concentration observed for juveniles was 1.40 ug Se/g (December 2, 2006) and 1.30 ug Se/g for the nauplii/cyst fraction on the same date. Biomass sample sizes for the smaller age-classes were low compared to the adult fraction and this may have had some influence on the selenium concentration determination. Sample sizes for all age-classes were increased substantially during the 2007 sampling programs.

Comparative Study of 2006 and 2007 Methods for Brine Shrimp Tissue Preparation.

Since 2006 brine shrimp tissue samples were lower than anticipated a comparative study was done in May 2007 to determine the cause of the lower than expected values. It was inferred that the low selenium concentration values were a result of excess residual salt in the samples. Because of this concern, an additional filtration step was added to the sample preparation to remove the salt. Samples collected and filtered were compared to samples collected and prepared according to the same methods used during the 2006 study.

The additional filtration procedure involved vacuum filtering the brine shrimp samples in the laboratory after the samples were sorted according to age-classes. The filtration step

was the final step just prior to freezing. The selenium results for brine shrimp tissue from these two methods were also compared to methods previously employed for the collection and preparation of brine shrimp samples (Brix et. al., 2004; Adams, 2005). In this third method (the Adams method) all age-classes are pooled together, brine shrimp are collected from the upper 1-2 meters of the water column by repeated net hauls, sample sizes are larger (10 to 30 grams minimum mass wet weight) than the mass typically obtained for Project 2b 2006 sampling season, and the residual GSL water is passively drained from the sample. Comparative methodological studies were done both in May and in August—the beginning and end of the 2007 study.

The results from these method comparisons are shown in Table 9. The results from the comparative study indicate that the brine shrimp tissue selenium values from 2006 are indeed artificially low. The results from 2007 for filtered samples are in alignment with other investigators, especially when the weighted averages of adult and nauplius fractions are combined. The results from the comparative studies in both May and August show an average concentration of 4.10 and 4.01 ug/g dry weight for the combined adult and nauplius fractions. The weighted average concentration is in general agreement with the Adams method, thereby lending credibility to the simplified method that is used by Adams for collecting brine shrimp samples for selenium analysis. The advantage of the Adams method is that it does not involved the multiple steps of separating age-classes of brine shrimp and the subsequent filtration step to remove residual salt water. With each laborious step time is involved and there is an added element of variability that is introduced. The disadvantage of the Adams method is that differences between the age-

classes cannot be discerned. Our results do indicate that the differences between adult and nauplius age-classes is substantial, and if comparisons are to be made with laboratory studies of a particular age-class, then it is necessary to separate brine shrimp on the basis of developmental stage.

Table 9. Selenium concentration in tissue from brine shrimp adults and nauplii. Results for the three methods of sample collection and preparation are shown. A calculated weighted average result for selenium in the adults and nauplii samples, that were analyzed separately, is also indicated.

Artemia Age-class	Filtered (Yes or No)	Program ID Comparative Study (CS)	Sample Date	Mean Selenium in ug/g	SD	Mean Wet Weight gm	Mean Dry Weight gm	% Moisture Content	Number of Samples
Adult	Yes	CS-1	5/8/07	4.92	0.81	6.12	0.74	88	6
Adult	[1]No	CS-1	5/8/07	1.33	0.25	7.71	0.89	89	5
Nauplius	Yes	CS-1	5/8/07	2.11	0.48	1.12	0.24	80	6
All	[2]No	CS-1	5/8/07	3.91	0.17	18.43	2.19	88	5
Adult	Yes	CS-2	8/31/07	4.68	0.25	6.51	0.98	85	5
Nauplius	Yes	CS-2	8/31/07	2.30	0.18	1.33	0.40	70	5
All	[2]No	CS-2	8/31/07	3.96	0.09	8.66	1.21	86	5
Calculated Selenium in Filtered Adult+Naup	**Yes**	**CS-1**	**5/8/07**	**4.10**					**12**
Calculated Selenium in Filtered Adult+Naup	**Yes**	**CS-2**	**8/31/07**	**4.01**					**10**
	[1]2006 Method **[2]Adams Method**								

Results from the May comparative study were used to derive a correction factor for the 2006 data. The application of such a correction factor itself introduces variability and

uncertainty and involves many assumptions. Because of these concerns the correction factor is applied only for very general purposes of comparing 2006 to 2007, with full recognition of the potential errors involved. The original and corrected values for the 2006 results are shown in Table 10. The mean corrected concentration of selenium in brine shrimp tissue from 2006 samples is 3.79 ug Se/g dw. This overall mean value does elevate the measured selenium in brine shrimp tissue from the 2006 season into a range that is more consistent with other reported values.

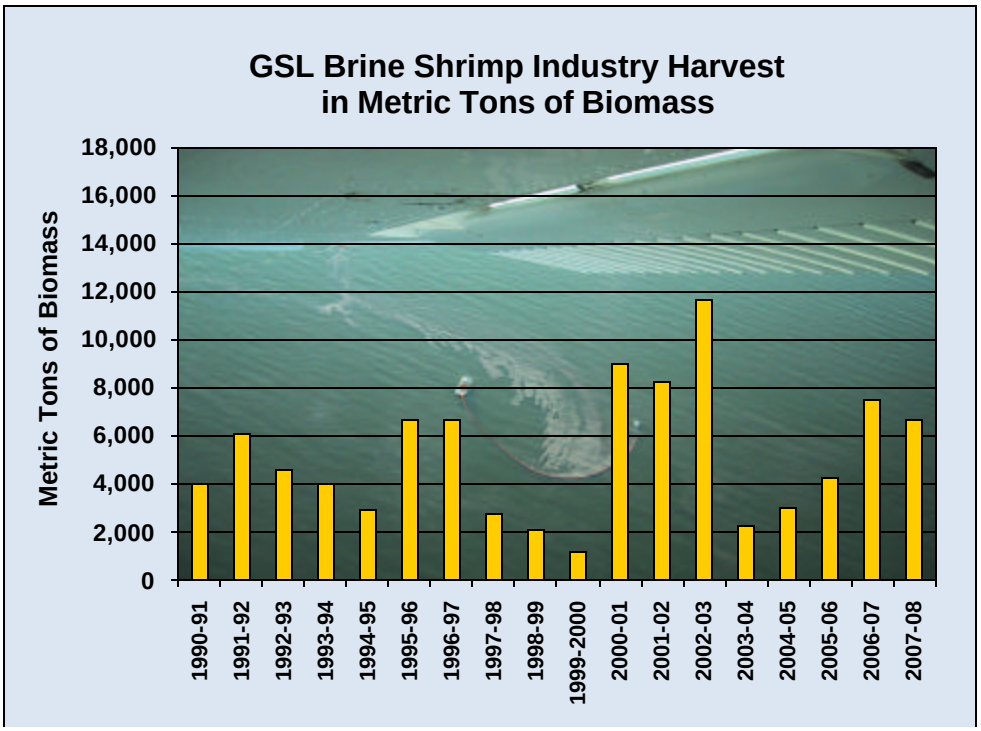
Table 10. Selenium in brine shrimp adult tissue for 2006 and 2007 samples. 2006 samples are shown as determined analytically and with a correction factor applied. The Correction factor was derived from comparative studies in which the influence of sample preparation on apparent tissue selenium concentration was determined.

DATE	Adult Selenium ug Se/g	Adult Selenium X CF ug Se/g	N
April 30, 2006	2.19	6.78	7.00
May 4, 2006	1.18	3.67	8.00
May 12, 2006	0.50	1.56	6.00
May 24, 2006	1.56	4.82	9.00
June 22, 2006	0.98	3.02	9.00
July 10, 2006	1.03	3.19	6.00
July 27, 2006	0.97	2.99	6.00
August 23, 2006	0.83	2.57	6.00
August 28, 2006	0.76	2.34	6.00
September 24, 2006	1.41	4.38	5.00
October 14, 2006	0.76	2.35	6.00
November 20, 2006	1.35	4.20	6.00
December 2, 2006	1.87	5.79	6.00
January 27, 2007			
March 15, 2007			
May 4, 2007	3.79	3.79	6.00
May 8, 2007	4.92	4.92	12.00
May 23, 2007	4.16	4.16	6.00
June 9, 2007	5.21	5.21	6.00
June 27, 2007	3.37	3.37	6.00
July 27, 2007	4.90	4.90	4.00
August 21, 2007	3.76	3.76	6.00
August 31, 2007	4.68	4.68	10.00
2006 Results	**1.20**	**3.79**	
2007 Results	**4.32**	**4.32**	

The Great Salt Lake Brine Shrimp Industry, Selenium Load in Brine Shrimp and Selenium Removal from GSL via Commercial Harvesting of Cysts.

A commercial brine shrimp harvesting industry has been involved in the removal of brine shrimp biomass and cysts since the 1950's. This industry has been a strong proponent and financial supporter of basic ecological research on the GSL. The royalty revenues and permit renewal fees from the brine shrimp industry have provided the financial basis for the highly successful Great Salt Lake Ecosystem Project (DWR). The brine shrimp industry was started by Mr. C.C. Sanders, of Sanders Brine Shrimp Co. in 1950 (Sturm, Sanders & Allen, 1980). From 1952 to 1988 there were generally only four brine shrimp harvesting companies working on the GSL. After 1988 the number of companies expanded in earnest—the number of companies increased until it reached a peak of 32 companies, and a total of 79 harvesting permits, in 1996. Although the number of companies has decreased since 1996, the number of permits remains the same. The brine shrimp industry has harvested from as little as 1.9 metric tons of brine shrimp cysts to a maximum of almost 12,000 metric tons during the 2000-2001 harvest season. The harvest results for the brine shrimp industry from 1990 to 2007 are shown in Figure 47.

Figure 47. Commercial brine shrimp cyst harvest results from 1990 to 2008. Values are reported in metric tons and are taken from harvest reports submitted to the State of Utah Division of Wildlife Resources. An aerial view of a harvesting operation underway is visible in the graph background.



Commercial harvesters of brine shrimp endeavor to selectively remove only the floating cysts and to avoid collecting any of the live brine shrimp. This is done by means of a harvesting vessel that tows floating containment barrier across the surface of the GSL consolidating the floating masses of cysts (Figure 48) and leaving behind the brine shrimp. The cysts are then pumped onto transport vessels by means of large filter sacks. The brine shrimp adults and other age-classes that are inadvertently collected are discarded back into the GSL to continue their lifecycle.

Figure 48. Brine shrimp harvesting vessel with consolidated cysts enclosed by floating containment barrier. The estimated haul from this collection of cysts is 12 to 14 tons wet weight.

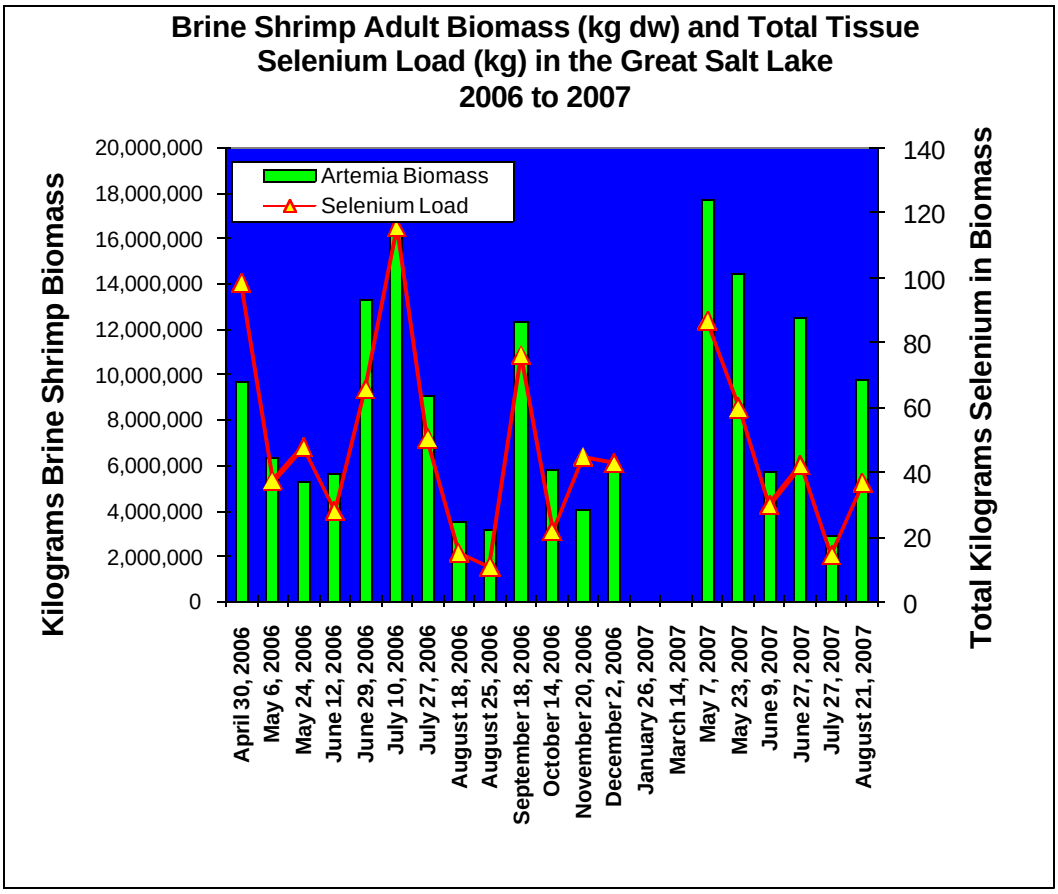
Because of the need to account for the mass balance of selenium in the GSL, it is necessary to calculate the removal quantity of selenium from the GSL via the brine shrimp harvest. The average 2007 selenium concentration in the nauplii/cyst fraction is 2.42 ug Se/g and can be used to determine the selenium removal from the GSL by the brine shrimp industry. This value represents the approximate concentration of selenium in the cysts and is more relevant than the brine shrimp adult selenium tissue value because the vast proportion of the brine shrimp biomass that is removed from the GSL by the brine shrimp industry is cyst biomass.

Although we don't have precise figures for industry dry yields, a recovery of 23% dry yield could be expected for an average harvest season. The brine shrimp industry removed 7,549 metric tons of cysts over the 2006-2007 season and 6,726 metric tons during the 2007-2008 harvest season (DWR, 2007). Using a nauplii/cyst selenium concentration of 2.42 ug Se/g dw, and a dry yield of 23%, the annual removal of selenium would be 4.20 kg for 2006 and 3.74 kg for 2007. According to Naftz et al. (2007) daily selenium loading into the GSL is between 0.6 kg Se/day to 9.8 kg Se/day. With regard to these loading values for selenium into the GSL, the removal of selenium by the brine shrimp industry is seemingly inconsequential for the mass balance of selenium in the GSL—it is the equivalent of selenium loading from a single day.

Mass Balance of Selenium in Brine Shrimp Tissue

The estimated GSL selenium load in the entire adult brine shrimp population, on any particular sampling date during the 2007 sampling season, was between 14.35 kg and 87.02 kg over the entire lake, with an average selenium load of 45.06 kg. These values are based on *Artemia* biomass statistics (mg dw/L), South Arm GSL elevation-to-volume relationships as determined by Baskin (2005), and adult tissue selenium concentration (ug Se/g dw). The values shown for the 2006 season are recalculated from the 2006 selenium values for adult brine shrimp using a correction factor for salt content. The 2006 values should only be used as a general estimate due to the use of the correction factor.

Figure 49. Brine shrimp biomass and the calculated selenium tissue load are shown for each sampling program. The total biomass of brine shrimp in the South Arm of the GSL is derived from the population counts and elevation/volume relationships determined by Baskin (2005) in his extensive bathymetric survey of the GSL.

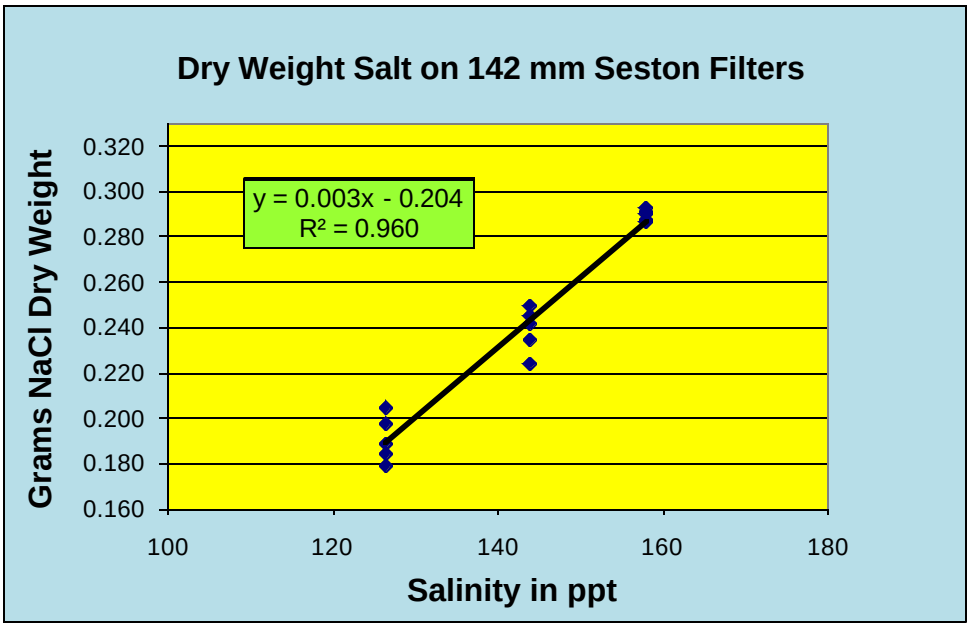


Selenium in Seston and Water during 2006 and 2007

Seston samples were collected by filtering between 1 and 5 liters of GSL water through a pre-weighed 0.45-micron (pore size), 142-mm, flatstock cellulose acetate filter. Filters and particulates, primarily algal cells, were freeze-dried and weighed. The entire filter and filtrate were then acid-digested and analyzed for selenium concentration. All sample weights were corrected for residual salt on filters based on the relationship between salinity and residual salt on filters shown in Figure 50. Blank filters were similarly

analyzed for selenium concentration to ensure that dry unused filters were below detection limits.

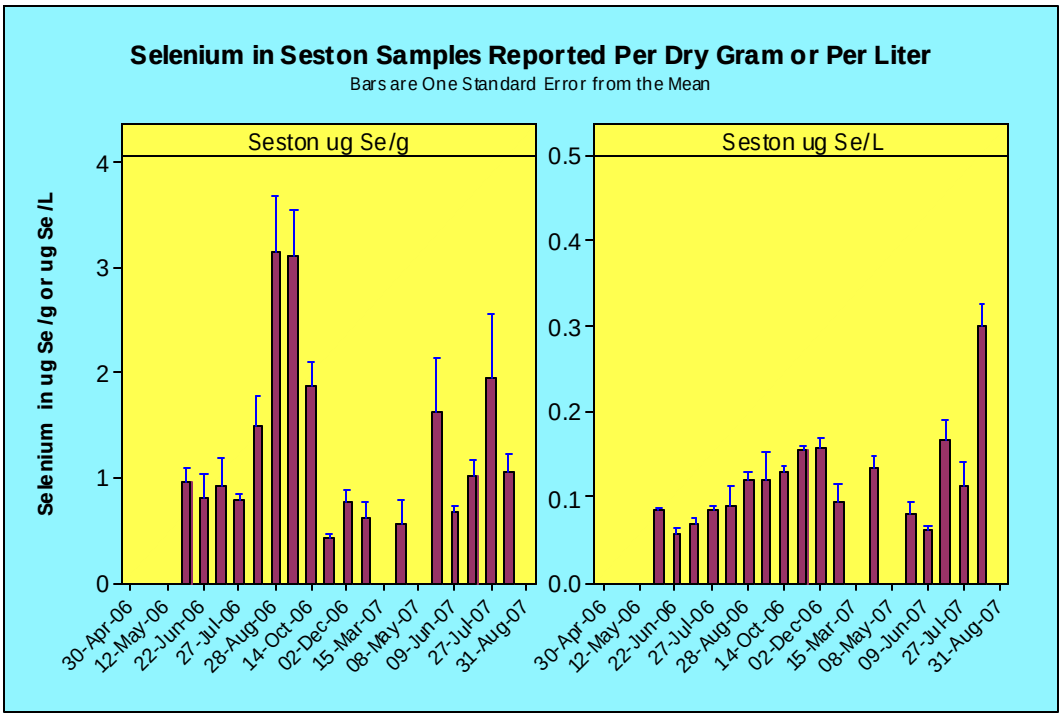
Figure 50. Correction curve for residual salt on 142 mm filters used to extract seston (particulates) from water samples. The curve was established using salt solutions that encompassed the range of salinity observed on the GSL over the 2006 and 2007 sample seasons. Residual salt was deducted from the final seston weight following which the selenium concentration in seston was recalculated on a dry weight basis.



The geometric mean for selenium in 2006 seston samples was 1.32 ug Se/g, and the arithmetic mean was 1.43 ug Se/g (Appendix 8.4). The geometric mean for selenium in 2007 seston samples was 0.86 ug Se/g, and the arithmetic mean was 1.08 ug Se/g. The highest selenium concentration in seston (3.16 ug Se/g) was on August 28, 2006, and the lowest concentration occurred on November 20, 2006 (0.44 ug Se/g) (Figure 51). The selenium concentration in seston on a volumetric basis was also calculated (the volume of GSL water filtered was recorded to the nearest 5 ml for all seston samples). The results show a geometric mean value for 2006 samples of 0.10 ug Se/L and an arithmetic

average of 0.11 ug Se/L. For the 2007 samples the geometric mean value was 0.13 ug Se/L and the mean concentration was 0.14 ug Se/L. The concentration of selenium in seston on a liquid volume basis is essentially the same as the calculated particulate fraction in water samples that are separately analyzed for total and dissolved selenium (total – dissolved = particulate). Our results for selenium in seston (ug Se/L) are very similar to the calculated particulate fraction for GSL water samples (0.14 ug Se/L) as reported by Johnson et al. (2007).

Figure 51. Selenium concentration in seston and water samples. Seston samples are expressed on a per-weight and per-volume basis. The concentration of selenium in seston (ug Se/L) shows an increasing temporal trend for both the 2006 and 2007 results. The 2006 trend corresponds to an increase in the phytoplankton population. This secondarily coincides with a decrease in grazing pressure following a reduction in the size of the *Artemia* population.



Spatial and temporal differences in seston selenium concentration were evaluated. There were no significant differences in terms of geographic region within each sample year for seston (Figures 52 and 53).

Figure 52. Selenium in seston samples collected in 2006 grouped according to geographic location.

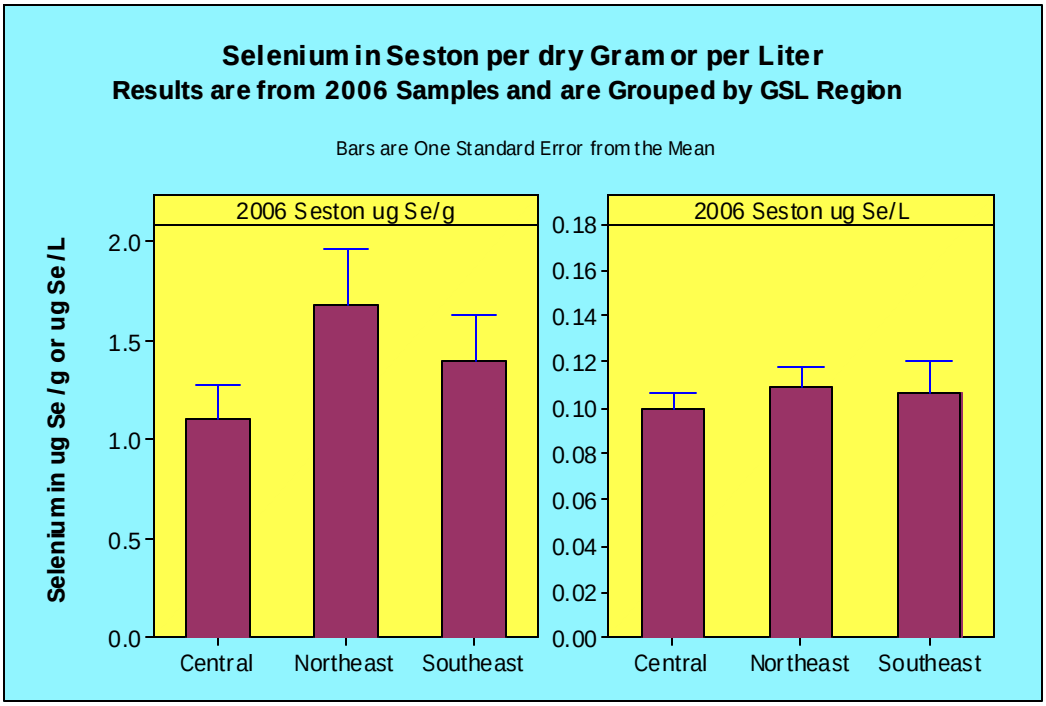
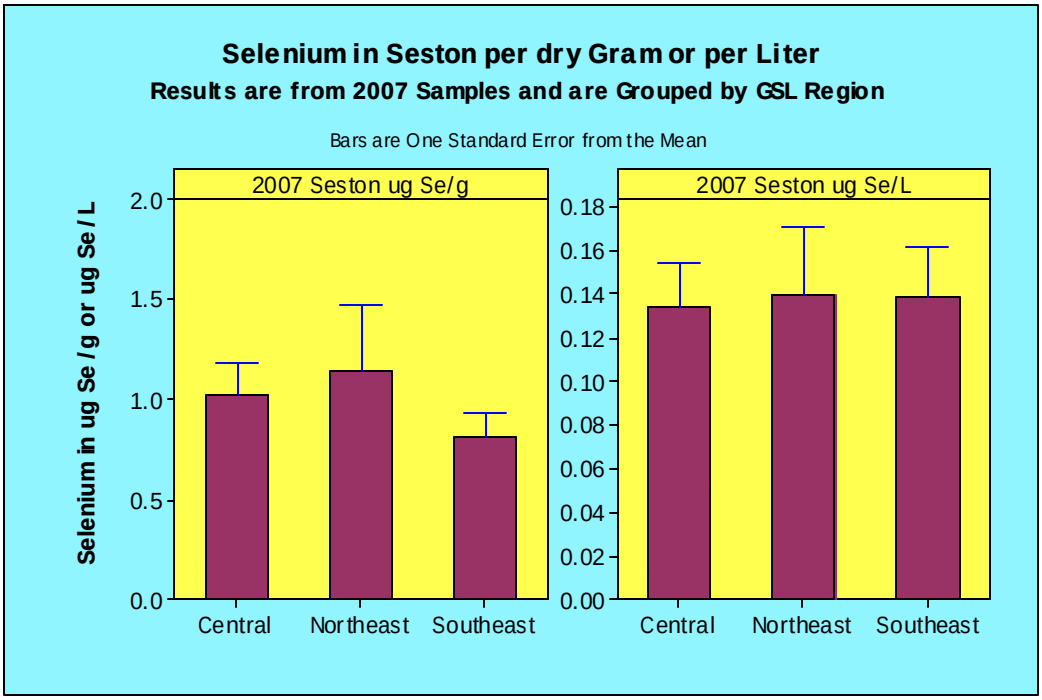


Figure 53. Selenium in seston samples collected in 2007 grouped according to geographic location.



Seston was evaluated according to the depth profile of the sample site (Figures 54 and 55). Grouping seston values according to depth profile did reveal a higher selenium concentration in the shallow sites from the 2006 samples. The average seston selenium concentration per liter for shallow sites in 2006 was 0.12 ug Se/L and it was significantly higher (P=0.048; 2, 60 DF) than the values for deep (0.10 ug Se/L) and medium depth sites (0.08 ug Se/L). There were no significant differences in seston values according to depth in 2007.

Figure 54. Selenium in seston samples collected in 2006 grouped according to depth profile.

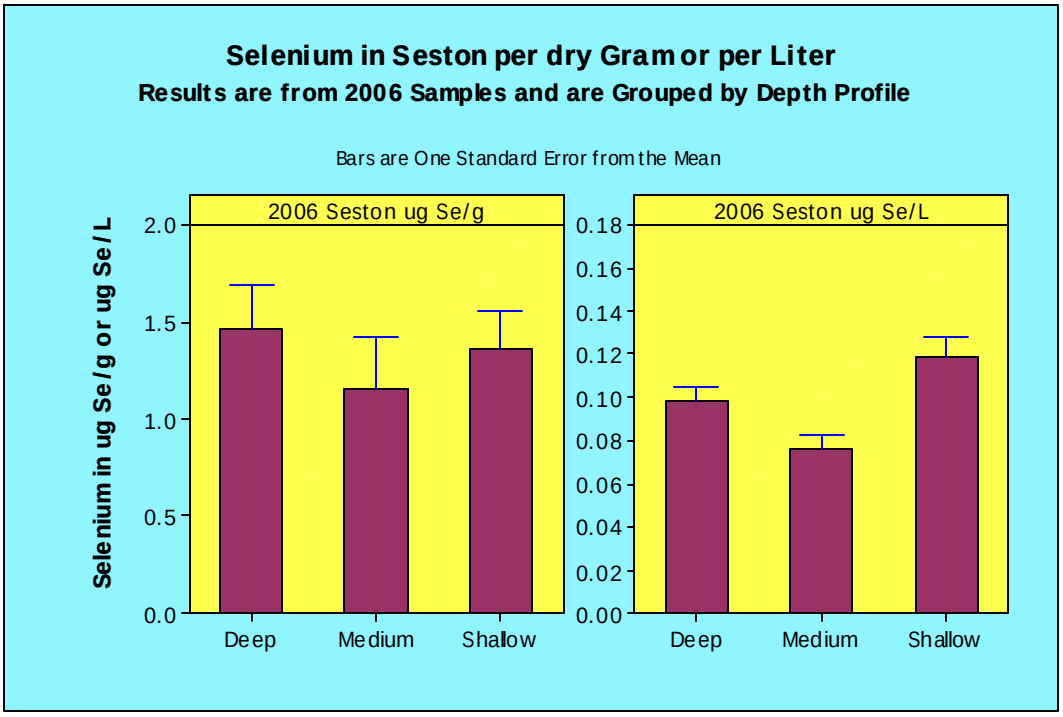
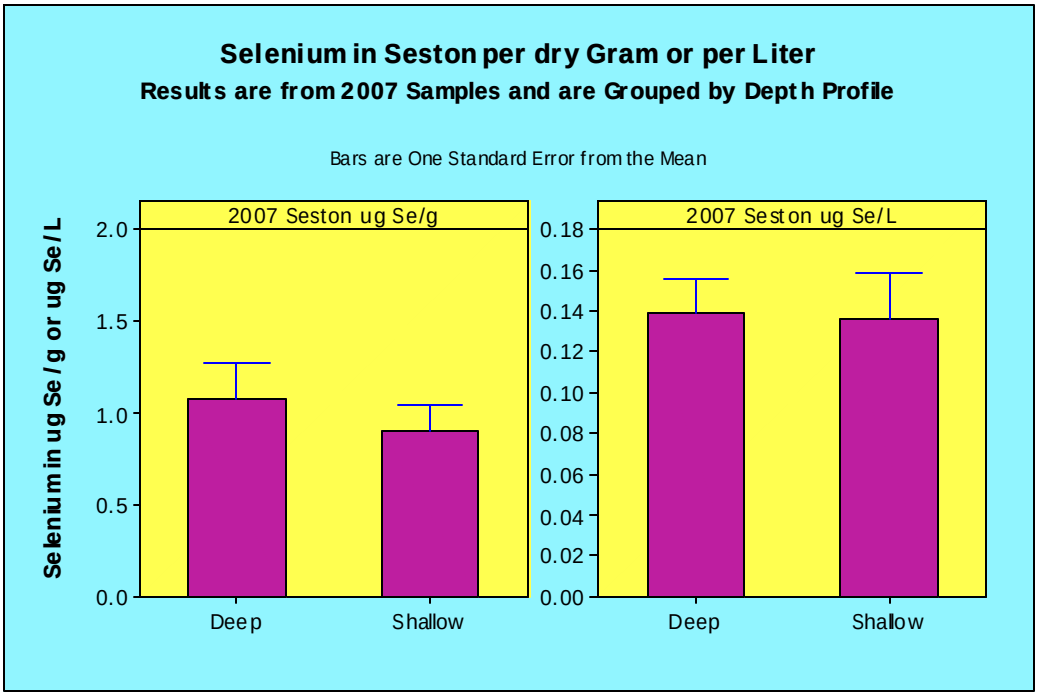
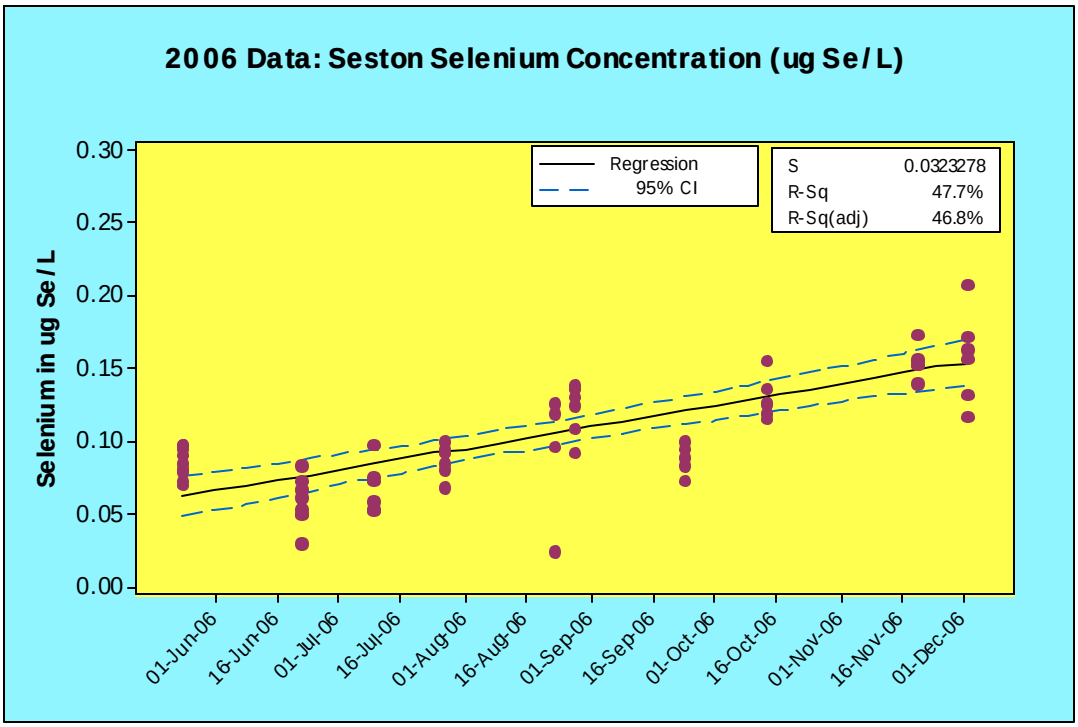


Figure 55. Selenium in seston samples collected in 2007 grouped according to depth profile.



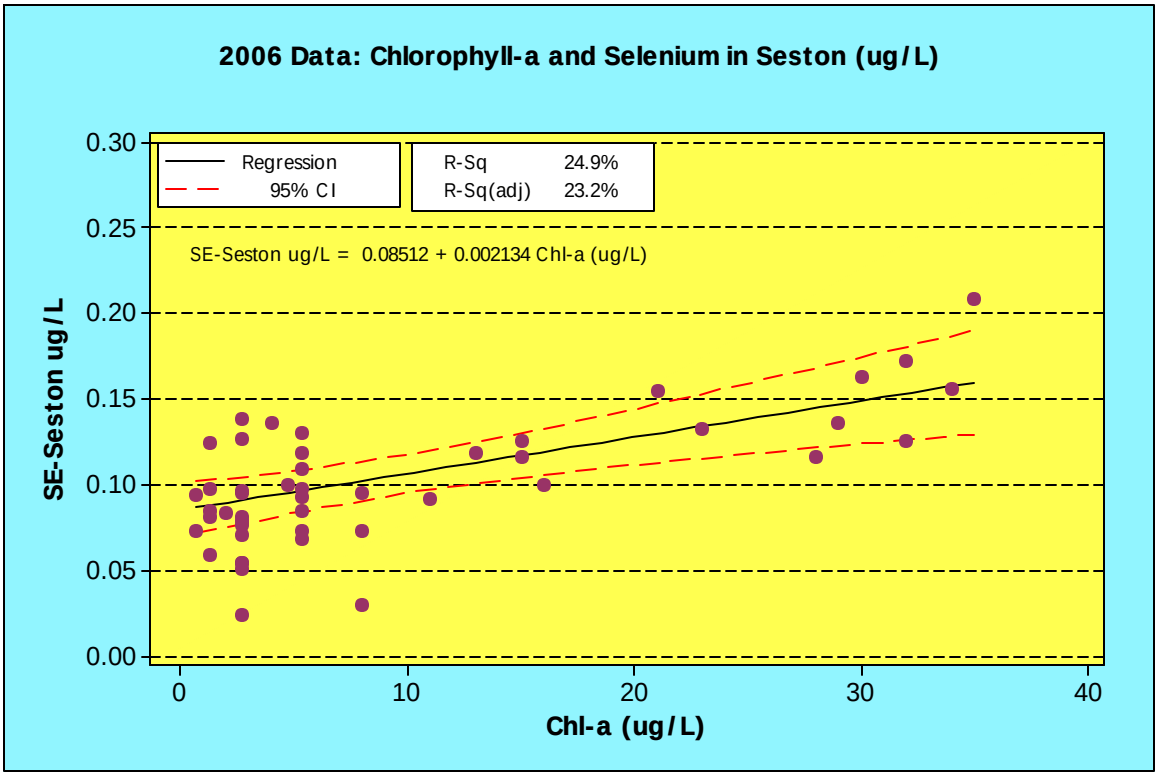
Temporally, the samples did substantially differ--there was a significant difference in the samples among the sampling dates (P=0.000; 16, 86 DF). Some interesting patterns in the seston data emerged. The concentration of selenium in the seston fraction on a dry weight basis increased sharply in August 2006 and then decreased substantially from October 2006 through March 2007. Alternatively, the seston concentration on a per volume basis showed a linear increasing trend from June 2006 to December 2006 (Figure 56). This increase generally followed the increase in algal growth over the same time period. This pattern of increasing particulate selenium was not as consistently observed from June to August 2007.

Figure 56. Selenium concentration in seston during 2006. From May to December 2006 there was a steady increase in the concentration of selenium in the particulate fraction of water.



This trend in 2006 can possibly be explained by the increase in algal growth, and therefore in the mass of algae per liter, attributable to decreased grazing pressure by the brine shrimp. To investigate this interpretation the seston results are plotted in terms of chlorophyll-a (Figure 57). There is a weak positive linear correlation ($R^2 = 0.24$) between increasing chlorophyll-a (i.e., increasing algal production) and the concentration of selenium in the particulate fraction of water. A linear relationship between chlorophyll-a and particulate selenium concentration in GSL water can be expected if chlorophyll-a is an accurate and linear measure of algal cell abundance, selenium uptake and loss in algal cells approaches equilibrium, and the pool of bioavailable selenium is not depleted by uptake into a rapidly growing algal population.

Figure 57. Relationship between chlorophyll-a concentration in GSL water and selenium concentration in suspended particulate matter. An increase in particulate selenium (ug Se/L) is expected to be correlated with algal population growth if there is no depletion in the selenium source and if uptake and loss approach equilibrium.



No such relationship was identified during 2007 for selenium in seston (ug Se/L) and chlorophyll-a.

Selenium in Water Samples

The results for selenium in unfiltered and filtered water varied temporally (Figure 58). Selenium in the water demonstrated a significantly increasing trend both within each year and across years. The temporal trend of selenium in water samples is more meaningfully evaluated within each year, rather than across years. There are annual or seasonal cycles in the GSL that may exert a profound influence on contaminant flux in the GSL. Some of

these cycles and seasonal events include spring run-off, phytoplankton production, brine shrimp population dynamics, evaporation cycles, hydrochemical cycling, thermal mixing, and weather events. The influence of these factors on the GSL hydrochemistry is both within and across years.

To discern some the trends in selenium in water samples the results for both total selenium and dissolved selenium in water samples were statistically evaluated for the entire 2-year study period and within each year. The results are shown in Figures 58 and 59 for total selenium in unfiltered GSL water and in Figures 60 and 61 for dissolved selenium in filtered GSL water.

Figure 58. Temporal trend of total selenium in unfiltered GSL water from May 2006 through August 2007.

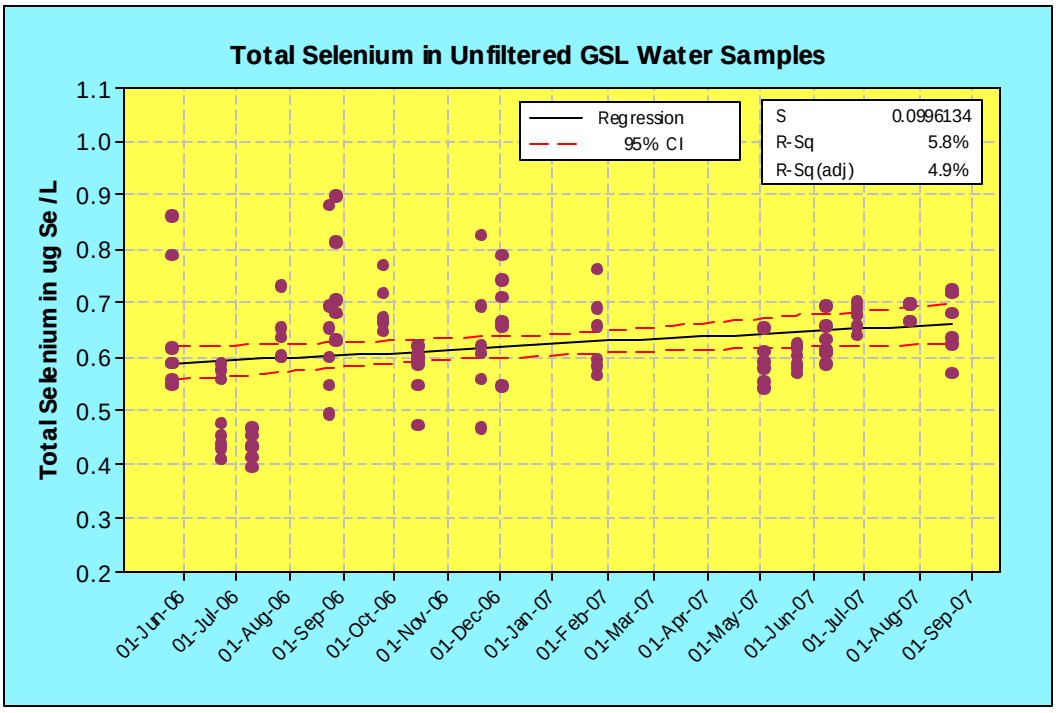
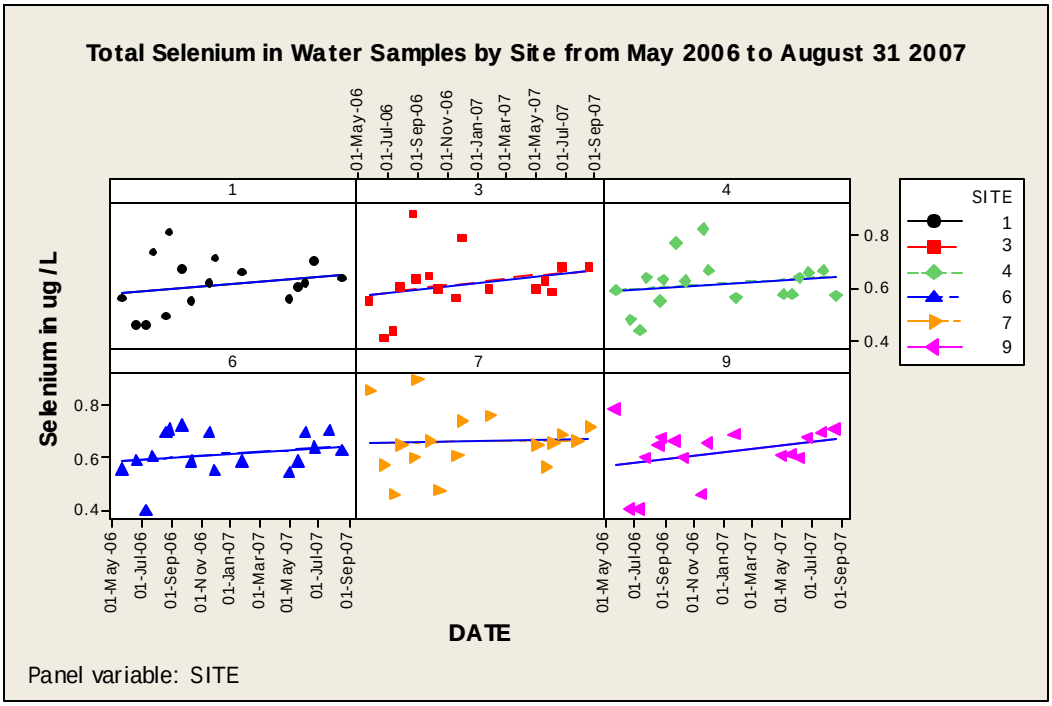


Figure 59. Temporal trend of total selenium in unfiltered GSL water from May 2006 through August 2007 for each sample site.

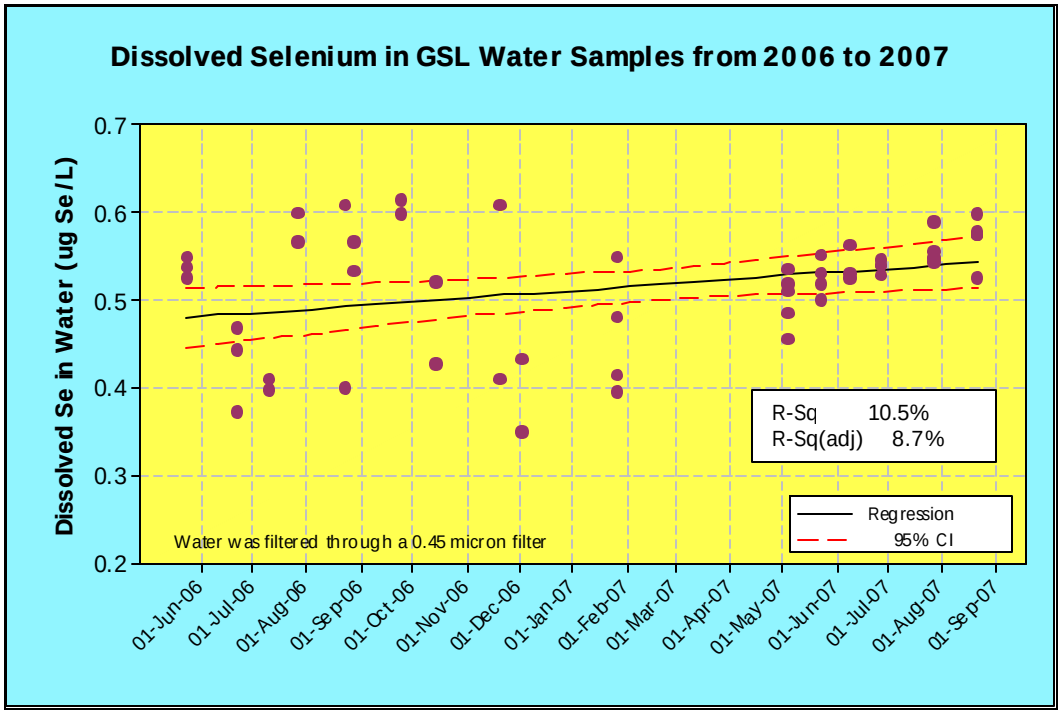


The temporal pattern for total selenium in water for the entire lake and for each sample site indicated a positive increase over time. However, there was considerable variability in the 2006 data that limited the ability to statistically identify a significant positive trend. Because total selenium in water samples includes the particulate fraction there can be overlapping events, such as phytoplankton population growth, that may obscure patterns of dissolved selenium flux in the water column.

Dissolved selenium values in GSL water samples from May 2006 to August 2007 are shown in Figure 60. The pattern for dissolved water showed a more definitive increasing trend in selenium concentration, especially when the 2007 results were evaluated

separately from the 2006 data. As was observed in the samples for total selenium, the 2006 values were considerably more variable than those in 2007. There were some issues of laboratory recoveries in 2006 that may have contributed to the outcome of the analyses. Sample collection, preparation, and handling procedures were essentially the same for both 2006 and 2007, though there were longer storage times and a lower storage temperature for some the early 2006 samples.

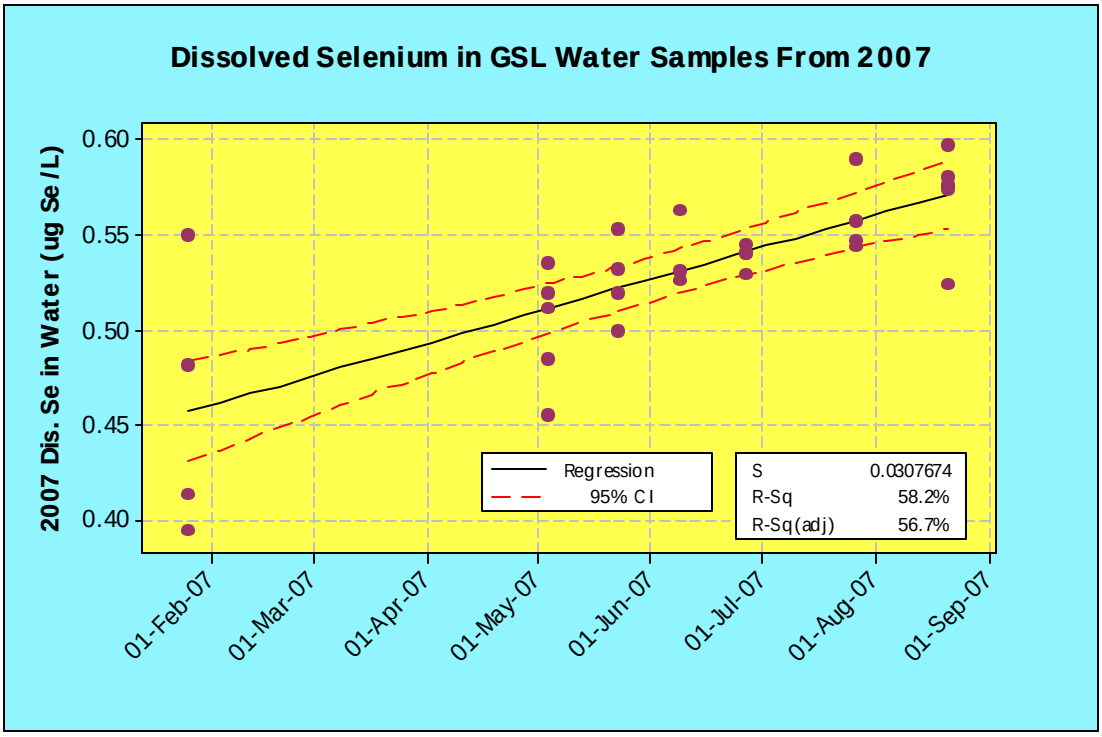
Figure 60. Dissolved selenium in filtered GSL water samples collected from May 2006 to August 2007.



The 2007 results for dissolved selenium in water samples did show a definitive increase in selenium concentration. There was a positive linear relationship between sample date and dissolved selenium in 2007 GSL water samples (Figure 61). The 2007 results for

dissolved selenium indicate an increase from an average of 0.46 ug Se/L in January to 0.57 ug Se/L in August 2007. According to Naftz et al. (2007) the expected increase over the 15 months from May 2006 to July 2007 for dissolved selenium in GSL water is 0.17 ug Se/L. The overall increase in dissolved selenium that we observed over the 8 month period from January to August 2007 of 0.11 ug Se/L does lend support to the estimate by Naftz et al. (2007).

Figure 61. Dissolved selenium in filtered GSL water samples collected from January 2007 to August 2007. A regression analysis of within year selenium concentration in water samples provides an improved interpretation and analysis of the trends.



The geometric mean of total selenium in unfiltered water for 2006 was 0.61 ug Se/L and the arithmetic mean was 0.60 ug Se/L (Appendix 8.5). The lowest and highest average

daily concentration of selenium in water from May 2006 to Aug 2007 was 0.43 ug Se/L (July 10, 2006) and 0.73 ug Se/L (August 28, 2006). An average net change from one sample period to the next for the entire study was 0.026 ug Se/L (Table 11).

Table 11. Net change in arithmetic mean selenium concentration (ug Se/L) in GSL water samples. Net change is determined on each subsequent sampling date for all sample locations. The result indicates a net increase of 0.026 ug Se/L.

Change in Average Water Selenium Concentration for All Sample Sites by Sampling Date.		
	ARITHMETIC	Net Change
DATE	MEAN	From Previous
		Date (ug/L)
April 30, 2006	No Data	No Data
May 4, 2006	No Data	No Data
May 12, 2006	No Data	No Data
May 24, 2006	0.634	xx
June 22, 2006	0.484	-0.150
July 10, 2006	0.418	-0.066
July 27, 2006	0.639	0.221
August 23, 2006	0.554	-0.085
August 28, 2006	0.718	0.164
September 24, 2006	0.691	-0.027
October 14, 2006	0.572	-0.119
November 20, 2006	0.630	0.058
December 2, 2006	0.668	0.037
January 27, 2007	0.644	-0.023
May 4, 2007	0.590	-0.055
May 23, 2007	0.597	0.008
June 9, 2007	0.633	0.036
June 27, 2007	0.676	0.043
July 27, 2007	0.684	0.008
August 21, 2007	0.660	-0.024
Avg Net Change		**0.026**

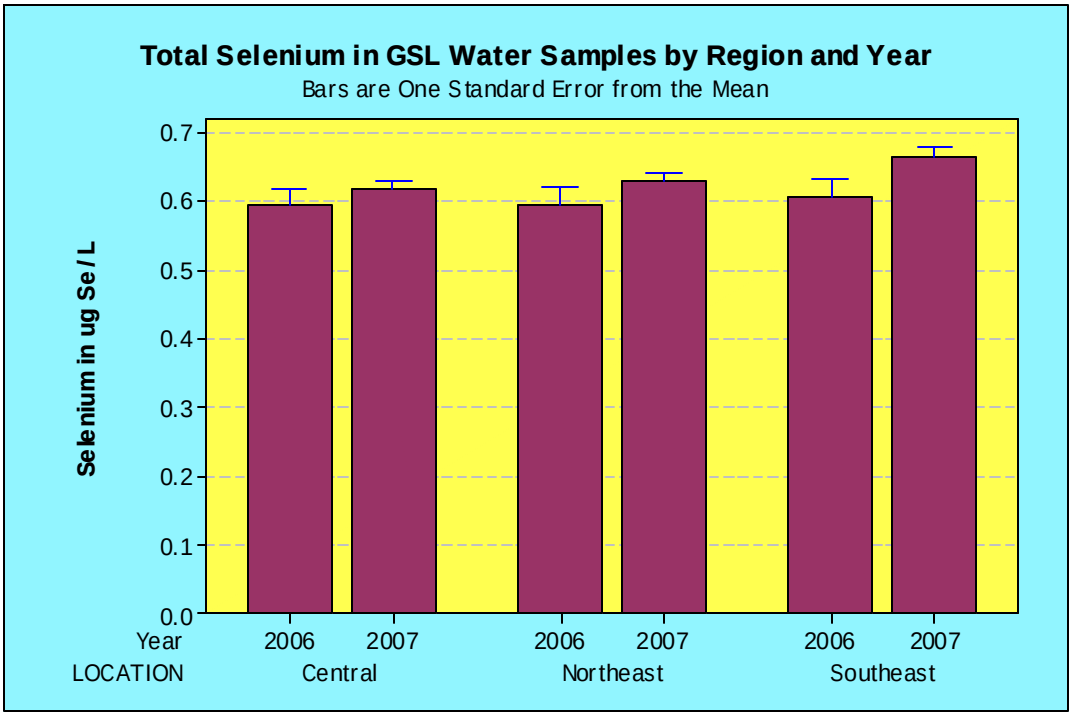
Mean Selenium Concentration in Unfiltered Water (ug Se/L)		
Year	Mean	Standard Deviation
2006	0.60	0.12
2007	0.64	0.05
2006 & 2007	0.61	0.10

The net change in total selenium in GSL water for each sequential sampling program varies considerably. In addition, the average net change in selenium concentration over time is substantially lower than the statistic comparing the overall change in selenium

from January 2007 to August 2007 for dissolved selenium in water (0.11 ug Se.L). Because of these differences in impression from dissolved and total selenium in water samples, on-going monitoring programs of selenium accumulation in the GSL should include both total and dissolved selenium assessments.

Spatial comparisons of total selenium in GSL water samples did not show any statistically significant difference across geographic regions (P = 0.736; df: 2, 63).

Figure 62. Selenium in unfiltered GSL water samples sorted by region and year.



The data suggest that there are temporal events that influence selenium loading into specific trophic compartments. The source of these temporal events is not entirely clear, but may be more apparent once the data from all research programs are integrated and interpreted collectively.

Trophic Transfer Relationships for Selenium in the GSL

For the purposes of understanding selenium dynamics in the GSL ecosystem it is essential to derive a quantifiable relationship between trophic levels. Selenium transfer between linked trophic components was evaluated using regression analysis. No

statistically significant polynomial regression relationship across all measurements of selenium in water, seston, and brine shrimp tissue was observed. The results for the 2006 and 2007 data are shown in Figures 63 and 64.

Figure 63. Scatter plot of selenium in brine shrimp tissue and seston or water for samples collected in 2007. There is no statistically significant polynomial regression relationship for selenium concentration between these trophic compartments. All P values were >0.100 and all R-squared values for the fitted lines were <0.10.

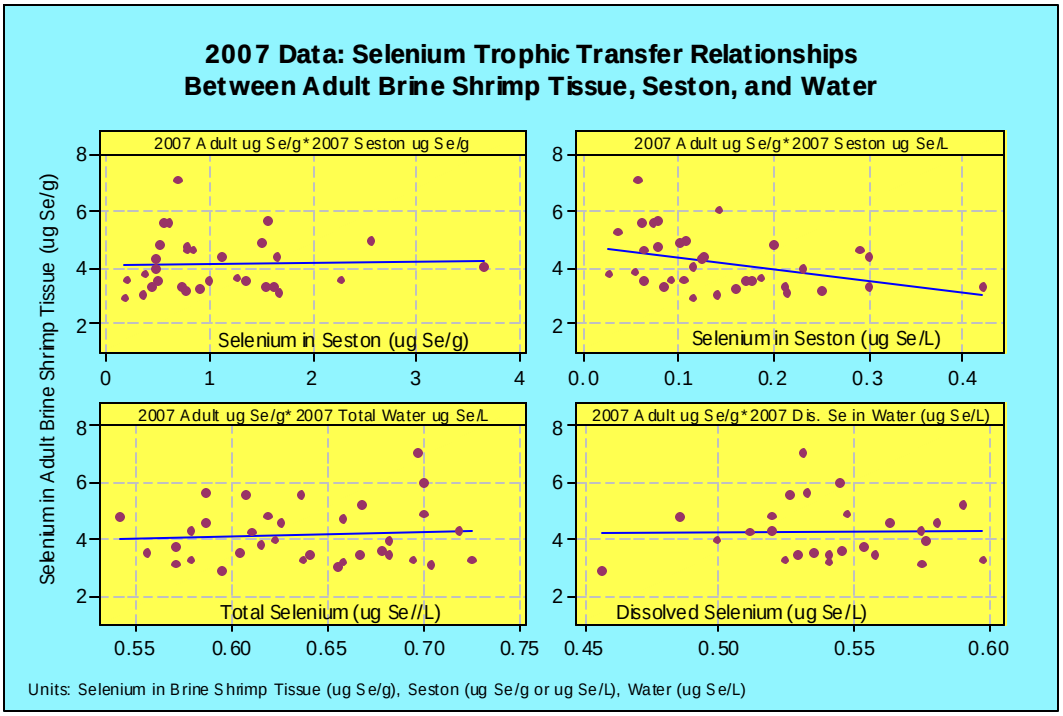
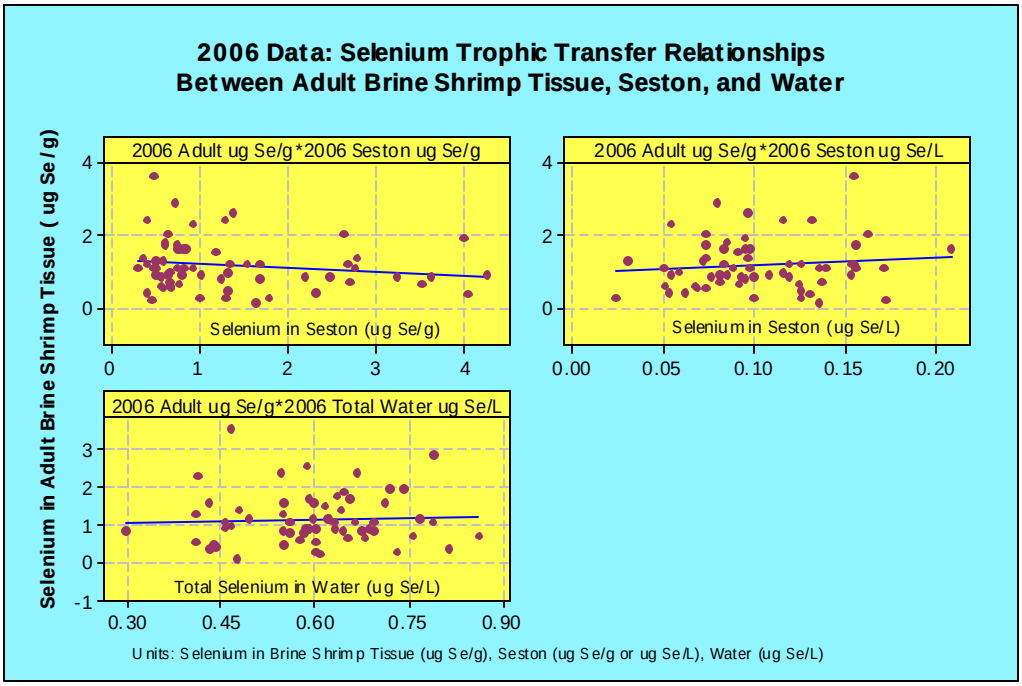


Figure 64. Scatter plot of selenium in brine shrimp tissue and seston or water for samples collected in 2006.



This outcome is not surprising given the small range of exposure concentrations encountered on the GSL. For example, the total range over which *Artemia* are exposed to dissolved selenium in the water is a mere 0.18 ug Se/L (0.39 to 0.57 ug Se/L) and the exposure range in the seston is 2.72 ug Se/g or 0.24 ug Se/L. It is indeed quite difficult to identify uptake patterns in selenium by invertebrates over such a small range of source concentrations.

Other investigators have previously reported a weak relationship between low concentrations of selenium in water and algae and brine shrimp tissue. In the presentation given to the science panel (November 2006), Dr. Marge Brooks indicated

that in the range of 1 to 11 ug Se/L selenium in water there is a poorly defined relationship with brine shrimp tissue selenium levels. Brooks further inferred that at these low environmental concentrations the brine shrimp are regulating their selenium levels in a manner largely independent of exposure concentration. The concentration of selenium in water for all sample dates and locations in our study was well below 11 ug Se/L. We concur with the observation of Brooks that there is a poorly defined relationship between brine shrimp tissue concentrations and exposure to selenium in water or algae at such low concentrations.

Because of the inability to derive a statistically meaningful polynomial regression relationship for selenium between trophic levels within the GSL, transfer factors are examined as an alternative means of interpreting the flow of selenium through the GSL food web. Transfer factors have been used by other authors to describe the relationship between selenium in soil and ephemeral pools (Byron et al., 2003). The partitioning values (Kds) from water (dissolved selenium) to seston were calculated for results from 2006 and 2007 (Table 12). Transfer factor relationships from seston and water to brine shrimp adults for co-located samples (by date and location) were determined for the 2007 results and are also reported in Table 12. The data from 2006 for selenium in adult brine shrimp was adjusted with a correction factor and then used to determine transfer factors for the combined 2006 and 2007 data. It should be reiterated that there is a increased uncertainty in the 2006 data as a result of the application of a correction factor. All statistics were calculated using least squares regression analysis.

The partition coefficients (Kd) for selenium transfer from dissolved water concentration to seston were quite similar for both 2006 and 2007 data. The 2007 Kd was 1841 and the 2006 Kd was 2254. Analyzing all seston values and all dissolved selenium values collectively gives a Kd of 1994. The transfer factor for selenium in seston (dry weight) to adult brine shrimp tissue was 2.57. As anticipated, the TF for the naupliar fraction was lower than for the adults and was 1.57. Combining all values for selenium in adult brine shrimp tissue, and after applying a correction factor to the 2006 data, the overall TF was 1.78. The trophic relationships between selenium in unfiltered and filtered water to adult brine shrimp tissue (BCF) are also listed. In 2007 the BCF values were 6494 for total selenium in water to brine shrimp tissue and 7634 for dissolved selenium to adult brine shrimp tissue. In naupllii these BCF values were 4014 for total selenium in water and 4818 for dissolved selenium. The combined 2006 and 2007 BCF values were 5964 for total selenium in water and 7613 for dissolved selenium. Residuals were analyzed for goodness of fit and for a normal distribution. Residual plots are shown in Figure 65 and 66 for the combined and corrected 2006 and 2007 adult selenium tissue data.

Table 12. Trophic transfer relationships for selenium in GSL water and biota. Statistics were calculated using least squares regression. P values for all statistics were P=0.000.

	TROPHIC TRANSFER RELATIONSHIPS Selenium in GSL Water and Biota		COEFFICIENT		
Data	**Response Source**	**Predictor Source**	**Kd**	**TF**	**BCF**
			Water (ppm Se) to Seston (ug Se/g)	Seston (ug Se/g) to BS (ug Se/g)	Water (ppm Se) to BS (ug Se/g)
2007	Adult Brine Shrimp	Seston (dry)		2.57	
2007	Adult Brine Shrimp	Unfiltered Water (Total Se)			6494
2007	Adult Brine Shrimp	Filtered Water (Dissolved Se)			7634
2007	Nauplii Brine Shrimp	Seston (dry)		1.57	
2007	Nauplii Brine Shrimp	Unfiltered Water (Total Se)			4014
2007	Nauplii Brine Shrimp	Filtered Water (Dissolved Se)			4818
2006 &2007	Adult Brine Shrimp (2006 data x CF)	Seston (dry)		1.78	
2006 &2007	Adult Brine Shrimp (2006 data x CF)	Unfiltered Water (Total Se)			5964
2006 &2007	Adult Brine Shrimp (2006 data x CF)	Filtered Water (Dissolved Se)			7613
2007	Seston (dry)	Filtered Water (Dissolved Se)	1841		
2006	Seston (dry)	Filtered Water (Dissolved Se)	2254		
2006 & 2007	Seston (dry)	Filtered Water (Dissolved Se)	1994		

LEGEND
CF: Correction Factor (used for 2006 adult brine shrimp Se concentration only)
BS: Brine Shrimp
SE: Selenium
TF: Transfer Factor
BCF: Bioconcentration Factor
Kd: Partition Coefficient

Figure 65. Normal probability plot for residuals from the regression analysis of selenium in adult brine shrimp tissue and seston selenium concentration.

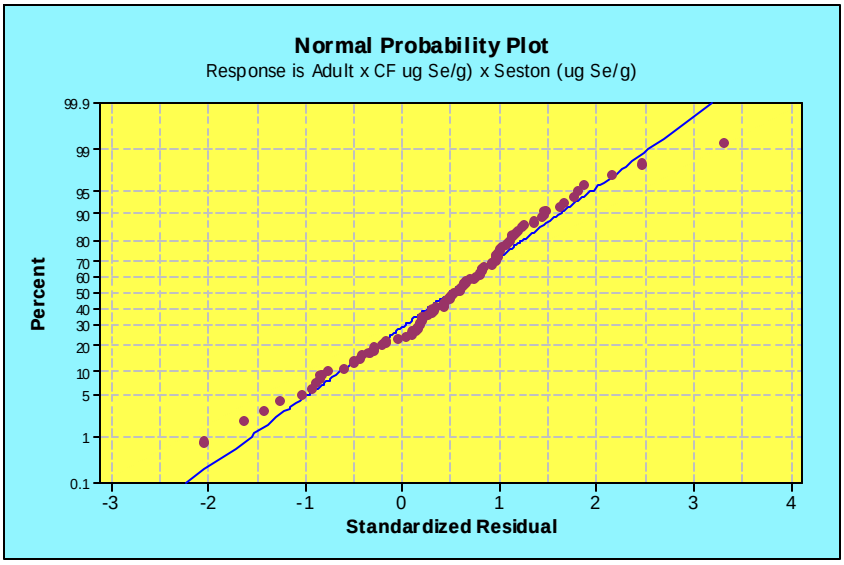
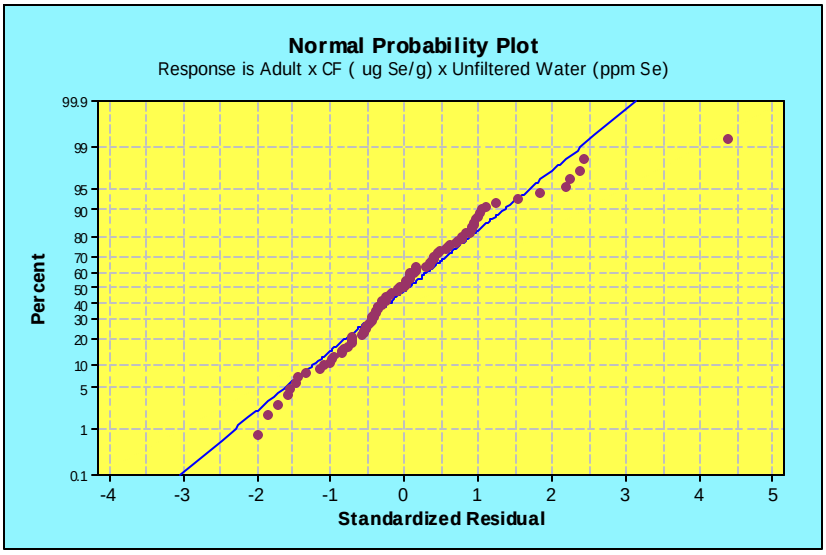


Figure 66. Normal probability plot for residuals from the regression analysis of selenium in adult brine shrimp tissue and total selenium concentration in unfiltered water.



CONCLUSION

This report contains summary findings from a pelagic study of the GSL investigating selenium in water, seston, and brine shrimp conducted from April 2006 to August 2007. In addition to a survey of selenium in water and biota, an extensive effort was made to document the population characteristics of resident brine shrimp and phytoplankton. Some aspects of the research were modified to improve the accuracy of results during the 2007 season.

The results of the brine shrimp population data show population cycles, reproductive output, biomass production, and cyst accumulation in the water column that are indicative of a 'healthy' brine shrimp population. All of the reproductive parameters investigated were within the range of values reported for the GSL over the past decade. There is no indication of any serious adverse effects on the brine shrimp population during 2006 and the spring of 2007. Brine shrimp biomass was available as a food source throughout the study period for aquatic and semi-aquatic birds.

The phytoplankton population was dominated by algae (e.g., Chlorophyceae) that are generally quite favorable and nutritious as a prey base for brine shrimp. The algal population demonstrated an ability to rapidly respond to release from *Artemia* grazing pressure and to effectively re-colonize the water column following the collapse of the brine shrimp population. Chlorophyll concentrations were lower than some previous years, but the winter concentration (41.7 ug Se/L) was sufficiently high to indicate an

abundant nutritional foundation for the emerging brine shrimp population in the spring of 2007.

The results from this two-year study indicate that selenium is found across all sample locations and sample dates in water, seston, and brine shrimp tissue. The mean concentration of selenium in water documented from May 2006 to December 2006 (0.60± 0.11 ug Se/L) corresponds well to the results of other concurrent studies (0.56 ± 0.18 ug Se/L) (Naftz et al., 2007; Johnson et al., 2007). The cumulative net change in total selenium in unfiltered water for all sample locations that were surveyed over this same time period in 2006 was an increase of 0.098 ug Se/L. The mean concentration of selenium in unfiltered GSL water from January 2007 to August 2007 was 0.64 ±0.05 ug Se/L, and the dissolved concentration of selenium in GSL water was 0.53 ±0.05 ug Se/L. The dissolved selenium concentration in filtered GSL water increased from January to August 2007 by 0.11 ug Se/L.

The average dry-weight selenium concentration in seston for 2006 was 1.43 ± 0.58 ug Se/g and for 2007 it was 1.08 ± 0.57 ug Se/g. Seston selenium values were alternatively used to determine the particulate fraction of selenium in the water phase. The average seston value per liter of GSL water filtered in 2006 was 0.11 ± 0.03 ug Se/L and for 2007 it was 0.14 ± 0.04 ug Se/L. This is in agreement with values reported by Johnson (2007) for the particulate fraction of GSL water (0.14 ug Se/L).

The measured concentration of selenium in adult brine shrimp tissue in 2006 (1.18 ug Se/g) was about 1.4 ug Se/g below previous studies on the GSL (Brix et al., 2004; Adams, 2005). Procedurally there were differences in the handling, cleaning, and sorting of brine shrimp in our study relative to others that may have had some effect on the selenium calculations. It was determined that residual salt in the 2006 adult brine shrimp samples resulted in artificially low values. A correction factor was applied to the 2006 data to allow for some comparisons to 2007 results. The mean corrected value for 2006 brine shrimp adults was 3.71 ug Se/g. Brine shrimp adults collected in 2007 showed a mean concentration of 4.32 $\pm$ 0.95 ug Se/g, while the value for nauplii was 2.42 $\pm$ 0.53 ug Se/g.

Younger age-classes of brine shrimp were analyzed for tissue selenium, and the results show substantially lower concentrations than those found for adults (53.8% of adults). The average selenium concentration in brine shrimp collected and analyzed were below the critical 5 mg/kg dietary level for protection of birds. However, there may be concerns among the brine shrimp industry members because the risk level for fish begins at 3.0 ug Se/g for diet items (Hamilton, 2003; Hamilton, 2004). The cyst level remains below this threshold at 1.77 ug Se/g, but the potential use of GSL brine shrimp biomass as a food source for finfish may already be compromised by the level of selenium.

Trophic transfer relationships were determined for selenium from water to seston and from seston to brine shrimp. The results from the 2007 study show a Kd of 1841 for dissolved selenium in water to seston. The transfer factor of selenium from seston to

adult brine shrimp is 2.57. The bioconcentration factor (BCF) for total selenium in GSL water to adult brine shrimp tissue is 6494 and the BCF for dissolved selenium is 7634. These values are our best current estimate of the trophic relationships for selenium in water, seston and adult brine shrimp.

The draft report submitted for this study in 2007 did not find the trophic transfer relationships to be sufficiently robust to use for management purposes. In contrast, the improved sample preparation methods in the 2007 study, consistency of the results with other concurrent research investigations on the GSL, and the results from inferential statistics all lend substantial credibility to the results from 2007. The trophic transfer relations can, and should, be used for management purposes and for advancing our understanding of the dynamics of selenium in the GSL ecosystem.

APPENDIX 1.1: DESCRIPTIVE STATISTICS FOR LIMNOLOGICAL CONDITIONS

Dissolved Oxygen Expressed as Percent Saturation

Dissolved Oxygen (% Saturation) by Sample Depth						
		April 2006 to June 2007				
DEPTH IN METERS	MEAN	STD DEV	CV	MIN	MAX	N
1	90.7	32.1	35.4	27.0	211.0	135
2	99.2	40.7	41.0	42.7	214.0	45
3	77.7	28.4	36.6	12.0	144.9	90
5	66.7	30.2	45.3	0.2	148.4	90
6	61.2	26.3	43.1	0.7	107.3	90
7	1.8	2.2	120.8	0.1	8.9	45
8	0.7	0.2	28.6	0.5	0.9	45

Salinity in g/L

Salinity by Sample Depth						
		April 2006 to June 2007				
DEPTH IN METERS	MEAN	STD DEV	CV	MIN	MAX	N
1	129.1	10.9	8.5	110.0	147.2	135
2	129.2	8.3	6.4	118.0	144.0	45
3	129.1	9.9	7.7	111.0	146.0	90
5	131.5	9.4	7.1	116.0	150.0	90
6	140.0	9.8	7.0	120.0	165.0	90
7	160.7	25.9	16.1	120.2	225.0	45
8	192.0	22.4	11.6	152.0	233.0	45

APPENDIX 1.2: DESCRIPTIVE STATISTICS FOR LIMNOLOGICAL CONDITIONS

Temperature in Degrees Centigrade

Water Temperature (degrees Centigrade) by Sample Depth						
		April 2006 to June 2007				
DEPTH IN METERS	MEAN	STD DEV	CV	MIN	MAX	N
1	18.7	8.3	44.4	(2.0)	29.5	135
2	17.4	9.7	55.8	(1.9)	28.8	45
3	18.5	8.0	43.2	(2.1)	28.4	90
5	17.8	8.0	45.0	(2.0)	28.2	90
6	17.9	9.1	51.0	(2.0)	28.1	90
7	15.7	5.9	37.4	2.3	25.1	45
8	13.3	4.3	32.4	4.0	19.8	45

APPENDIX 2.1: DESCRIPTIVE STATISTICS FOR *ARTEMIA* POPULATION

Adult *Artemia* Statistics

Artemia Adult (M+F) per Cubic Meter

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	1266	934	74	676	3341	7
May 6, 2006	913	318	35	411	1253	8
May 24, 2006	828	437	53	335	1879	9
June 12, 2006	1127	671	60	462	2040	6
June 29, 2006	2426	1515	62	921	5829	9
July 10, 2006	3722	7152	192	396	18307	6
July 27, 2006	674	939	139	93	2557	6
August 18, 2006	550	958	174	34	2498	6
August 25, 2006	205	126	61	102	411	6
September 18, 2006	2054	3725	181	185	9626	6
September 24, 2006	710	452	64	362	1468	5
October 14, 2006	619	492	79	0	1383	6
November 20, 2006	844	281	33	540	1222	6
December 2, 2006	582	463	80	159	1485	6
January 26, 2007	0	0	0	0	0	6
May 7, 2007	1516	1672	110	115	3819	6
May 23, 2007	1297	1461	113	170	4099	6
June 9, 2007	431	399	93	149	1218	6
Arithmetic Mean	**1,127**					
Standard Dev.	**2,039**					
Median	**620**					

APPENDIX 2.2: DESCRIPTIVE STATISTICS FOR *ARTEMIA* POPULATION

Adult *Artemia* Statistics

Artemia Adult Male per Cubic Meter

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	626	619	99	258	2,015	7
May 6, 2006	465	215	46	191	772	8
May 24, 2006	327	242	74	140	958	9
June 12, 2006	563	326	58	213	922	6
June 29, 2006	1,178	812	69	492	3,082	9
July 10, 2006	1,767	3,334	189	189	8,565	6
July 27, 2006	404	534	132	62	1,468	6
August 18, 2006	306	483	158	21	1,283	6
August 25, 2006	131	81	61	67	286	6
September 18, 2006	1,045	1,899	182	132	4,904	6
September 24, 2006	345	173	50	222	645	5
October 14, 2006	363	320	88	0	887	6
November 20, 2006	426	157	37	244	669	6
December 2, 2006	266	233	88	83	726	6
January 26, 2007	0	0	0	0	0	6
May 7, 2007	862	936	109	76	2,357	6
May 23, 2007	524	541	103	127	1,553	6
June 9, 2007	190	173	91	79	535	6
Arithmetic Mean	**556**					
Standard Dev.	**988**					
Median	**284**					

APPENDIX 2.3: DESCRIPTIVE STATISTICS FOR *ARTEMIA* POPULATION

Adult *Artemia* Statistics

Artemia Adult Female per Cubic Meter

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	640	323	50	348	1,326	7
May 6, 2006	448	142	32	220	642	8
May 24, 2006	501	227	45	195	921	9
June 12, 2006	564	356	63	249	1,133	6
June 29, 2006	1,248	736	59	387	2,747	9
July 10, 2006	1,955	3,818	195	207	9,742	6
July 27, 2006	270	405	150	29	1,089	6
August 18, 2006	244	476	195	13	1,215	6
August 25, 2006	73	57	78	34	165	6
September 18, 2006	1,008	1,827	181	44	4,722	6
September 24, 2006	365	282	77	141	823	5
October 14, 2006	256	176	69	0	496	6
November 20, 2006	418	131	31	295	611	6
December 2, 2006	316	235	74	76	760	6
January 26, 2007	0	0	0	0	0	6
May 7, 2007	654	819	125	38	2,122	6
May 23, 2007	773	921	119	42	2,546	6
June 9, 2007	241	228	95	70	683	6
Arithmetic Mean	**571**					
Standard Dev.	**1,064**					
Median	**331**					

APPENDIX 3.1: DESCRIPTIVE STATISTICS FOR *ARTEMIA* POPULATION

Nauplii, Metanauplii, and Juvenile *Artemia* Statistics

Artemia Nauplii per Cubic Meter

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	684	595	87	159	1,697	7
May 6, 2006	935	1,559	167	0	4,444	8
May 24, 2006	341	232	68	0	723	9
June 12, 2006	694	640	92	127	1,697	6
June 29, 2006	21,737	15,521	71	8,381	52,980	9
July 10, 2006	326	558	171	0	1,414	6
July 27, 2006	3,847	3,730	97	931	10,183	6
August 18, 2006	2,890	285	10	2,418	3,235	6
August 25, 2006	1,273	635	50	358	1,949	6
September 18, 2006	251	226	90	1	643	6
September 24, 2006	194	222	115	30	557	5
October 14, 2006	966	1,433	148	0	3,819	6
November 20, 2006	1,584	1,306	82	91	3,501	6
December 2, 2006	1,033	1,599	155	0	4,243	6
January 26, 2007	0	0	0	0	0	6
May 7, 2007	36,417	30,339	83	2,864	70,873	6
May 23, 2007	34,948	29,553	85	7,081	73,988	6
June 9, 2007	737	830	113	68	1,856	6
Arithmetic Mean	**6,222**					
Standard Dev.	**15,114**					
Median	**733**					

APPENDIX 3.2: DESCRIPTIVE STATISTICS FOR *ARTEMIA* POPULATION

Nauplii, Metanauplii, and Juvenile *Artemia* Statistics

Artemia Meta-Nauplii per Cubic Meter

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	1112	763	69	424	2387	7
May 6, 2006	443	533	120	0	1697	8
May 24, 2006	751	646	86	106	2015	9
June 12, 2006	657	777	118	71	2130	6
June 29, 2006	38312	43935	115	8465	147707	9
July 10, 2006	2146	1903	89	341	5445	6
July 27, 2006	35563	32367	91	2400	95470	6
August 18, 2006	19133	13423	70	6434	43803	6
August 25, 2006	9948	3173	32	7637	15276	6
September 18, 2006	1125	1034	92	318	3050	6
September 24, 2006	695	682	98	0	1667	5
October 14, 2006	835	513	61	182	1697	6
November 20, 2006	2792	3165	113	364	8910	6
December 2, 2006	1003	808	81	0	2122	6
January 26, 2007	0	0	0	0	0	6
May 7, 2007	10973	11650	106	110	33357	6
May 23, 2007	3052	5271	173	0	13366	6
June 9, 2007	1172	1537	131	3	4010	6
Arithmetic Mean	**7,731**					
Standard Dev.	**18,675**					
Median	**1,040**					

APPENDIX 3.3: DESCRIPTIVE STATISTICS FOR *ARTEMIA* POPULATION

Nauplii, Metanauplii, and Juvenile *Artemia* Statistics

Artemia Juveniles per Cubic Meter

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	3,715	4,954	133	759	14,872	7
May 6, 2006	2,647	2,641	100	282	8,537	8
May 24, 2006	1,362	539	40	296	2,089	9
June 12, 2006	1	3	245	-	8	6
June 29, 2006	4,307	2,535	59	1,781	9,848	9
July 10, 2006	417	688	165	13	1,800	6
July 27, 2006	27	42	157	1	110	6
August 18, 2006	855	1,962	229	0	4,857	6
August 25, 2006	433	395	91	-	1,034	6
September 18, 2006	1,739	3,106	179	9	8,013	6
September 24, 2006	111	142	128	6	299	5
October 14, 2006	105	123	117	-	320	6
November 20, 2006	1,132	777	69	524	2,673	6
December 2, 2006	1,799	2,239	124	364	6,269	6
January 26, 2007	0	0	0	0	0	6
May 7, 2007	1,243	1,337	108	25	3,556	6
May 23, 2007	929	1,311	141	13	3,479	6
June 9, 2007	587	266	45	185	980	6
Arithmetic Mean	**1,331**					
Standard Dev.	**2,218**					
Median	**536**					

APPENDIX 4.1: DESCRIPTIVE STATISTICS FOR *ARTEMIA* POPULATION

Total *Artemia* Abundance and Biomass

Total *Artemia* Abundance per Cubic Meter

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	6,778	5,754	85	2,375	19,327	7
May 6, 2006	4,938	3,539	72	931	11,481	8
May 24, 2006	3,282	1,406	43	1,528	6,309	9
June 12, 2006	2,479	1,756	71	887	5,150	6
June 29, 2006	66,781	52,356	78	26,491	193,081	9
July 10, 2006	6,611	9,344	141	1,432	25,553	6
July 27, 2006	40,111	31,956	80	3,740	98,404	6
August 18, 2006	23,428	13,004	56	9,077	47,310	6
August 25, 2006	11,858	3,198	27	8,569	17,098	6
September 18, 2006	5,169	7,255	140	679	19,518	6
September 24, 2006	1,709	1,101	64	520	2,970	5
October 14, 2006	2,525	2,365	94	796	7,220	6
November 20, 2006	6,353	3,781	60	2,492	12,211	6
December 2, 2006	4,416	3,841	87	851	9,778	6
January 26, 2007	0	0	0	0	0	6
May 7, 2007	50,149	42,003	84	3,114	109,826	6
May 23, 2007	40,226	34,761	86	8,100	92,509	6
June 9, 2007	2,926	2,329	80	775	6,956	6
Arithmetic Mean	**16,410**					
Standard Dev.	**28,444**					
Median	**4,381**					

APPENDIX 4.2: DESCRIPTIVE STATISTICS FOR *ARTEMIA* POPULATION

Total *Artemia* Abundance and Biomass

Artemia Biomass in mg/L

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	0.936	0.684	73	0.191	2.342	7
May 6, 2006	0.619	0.472	76	0.143	1.555	8
May 24, 2006	0.516	0.122	24	0.283	0.623	9
June 12, 2006	0.554	0.236	43	0.252	0.922	6
June 29, 2006	1.300	0.852	66	0.331	3.075	9
July 10, 2006	1.649	2.650	161	0.271	7.026	6
July 27, 2006	0.920	0.966	105	0.167	2.800	6
August 18, 2006	0.368	0.377	102	0.018	1.104	6
August 25, 2006	0.333	0.221	66	0.169	0.658	6
September 18, 2006						
September 24, 2006						
October 14, 2006	0.628	0.581	93	0.094	1.357	6
November 20, 2006	0.432	0.335	78	0.108	0.927	6
December 2, 2006						
January 26, 2007						
May 7, 2007	1.795	1.595	89	0.455	4.499	6
May 23, 2007	1.482	1.260	85	0.499	3.574	6
June 9, 2007	0.596	0.343	58	0.165	1.206	6
Arithmetic Mean	**0.770**					
Standard Dev.	**0.695**					
Median	**0.592**					

APPENDIX 5.1: DESCRIPTIVESTATISTICS FOR *ARTEMIA* POPULATION

Cyst Abundance, Cyst Brood Size, and Productivity

Cyst Abundance per Cubic Meter

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	5,343	3,519	66	1,432	9,653	7
May 6, 2006	3,228	1,707	53	926	6,172	8
May 24, 2006	5,088	2,689	53	2,459	10,502	9
June 12, 2006	18,865	17,659	94	1,768	49,644	6
June 29, 2006	9,148	12,007	131	891	39,381	9
July 10, 2006	36,794	45,876	125	11,138	128,988	6
July 27, 2006	14,868	20,678	139	3,000	56,857	6
August 18, 2006	31,015	21,832	70	13,820	72,255	6
August 25, 2006	27,384	21,711	79	10,986	70,187	6
September 18, 2006	28,353	20,225	71	9,229	61,736	6
September 24, 2006	41,742	24,357	58	15,578	81,906	5
October 14, 2006	52,966	68,931	130	5,864	187,118	6
November 20, 2006	18,697	13,708	73	1,955	35,748	6
December 2, 2006	35,990	16,235	45	16,730	52,773	6
January 26, 2007	3,976	3,044	77	1,641	9,759	6
May 7, 2007	22,311	29,013	130	273	62,054	6
May 23, 2007	18,067	13,175	73	7,425	43,643	6
June 9, 2007	16,195	12,654	78	6,205	37,915	6
Arithmetic Mean	**20,284**					
Standard Dev.	**26,188**					
Median	**10,744**					

APPENDIX 5.2: DESCRIPTIVE STATISTICS FOR *ARTEMIA* POPULATION

Cyst Abundance, Cyst Brood Size, and Productivity

Cyst Brood Size per Female w/Cysts

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006						
May 6, 2006						
May 24, 2006						
June 12, 2006						
June 29, 2006	111	18	16	93	151	9
July 10, 2006						
July 27, 2006	74	24	32	48	102	6
August 18, 2006	89	14	15	67	103	6
August 25, 2006	114	36	32	69	157	6
September 18, 2006	60	14	24	43	76	6
September 24, 2006	34	7	21	24	44	5
October 14, 2006	83	17	20	64	108	6
November 20, 2006	112	15	13	88	128	6
December 2, 2006	107	26	25	56	128	6
January 26, 2007						6
May 7, 2007	121	22	18	89	136	6
May 23, 2007	93	20	21	67	111	6
June 9, 2007	31	4	12	27	36	6
Arithmetic Mean	**87.34**					
Standard Dev.	**33.90**					
Median	**92.00**					

APPENDIX 5.3: DESCRIPTIVE STATISTICS FOR *ARTEMIA* POPULATION

Cyst Abundance, Cyst Brood Size, and Productivity

Productivity (Cyst Brood Size x # Females w/cysts) per Cubic Meter

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006						
May 6, 2006						
May 24, 2006						
June 12, 2006						
June 29, 2006	12,879	8,963	70	3,950	27,557	9
July 10, 2006						6
July 27, 2006	14,270	27,099	190	978	69,450	6
August 18, 2006	3,765	3,462	92	1,827	9,889	6
August 25, 2006	2,076	1,293	62	233	3,908	6
September 18, 2006	3,178	3,642	115	588	9,508	6
September 24, 2006	1,519	931	61	605	2,921	5
October 14, 2006	11,464	9,100	79	66	23,871	6
November 20, 2006	3,125	2,493	80	116	5,414	6
December 2, 2006	3,119	4,462	143	111	10,880	6
January 26, 2007						
May 7, 2007						
May 23, 2007	2,643	2,112	80	69	4,689	6
June 9, 2007	323	732	227	27	1,816	6
Arithmetic Mean	**5,533**					
Standard Dev.	**9,873**					
Median	**2,354**					

APPENDIX 6.1: COMPARATIVE STATISTICS FOR *ARTEMIA* POPULATION

Biomass, Cyst Brood Size, and Productivity by Sample Site

Artemia Biomass in mg/L by Sample Site						
		April 2006 to June 2007				
SITE	MEAN	STD DEV	CV	MIN	MAX	N
1	1.082	1.063	98.2	0.117	3.574	18
2	0.625	0.146	23.3	0.428	0.839	5
3	0.510	0.245	48.0	0.186	1.158	18
4	1.158	1.028	88.7	0.165	3.075	18
5	0.723	0.484	67.0	0.339	1.432	4
6	0.616	0.322	52.2	0.244	1.334	18
7	0.817	0.793	97.0	0.018	2.491	16
8	0.903	0.572	63.3	0.491	1.555	3
9	0.503	0.321	63.7	0.167	1.189	16
Arithmetic Mean	**0.770**					
Standard Dev.	**0.695**					
Median	**0.592**					

APPENDIX 6.2: COMPARATIVE STATISTICS FOR *ARTEMIA* POPULATION

Biomass, Cyst Brood Size, and Productivity by Sample Site

Cyst Brood Size by Sample Site						
		April 2006 to June 2007				
SITE	MEAN	STD DEV	CV	MIN	MAX	N
1	74	34	46	24	136	11
2	107			107	107	1
3	94	36	38	34	151	12
4	85	29	34	33	122	11
5	112			112	112	1
6	87	33	39	27	128	12
7	86	43	50	36	154	8
8	93			93	93	1
9	94	36	39	31	157	11

Arithmetic Mean	**87.34**
Standard Dev.	**33.90**
Median	**92.00**

APPENDIX 6.3: COMPARATIVE STATISTICS FOR *ARTEMIA* POPULATION

Biomass, Cyst Brood Size, and Productivity by Sample Site

Productivity per Cubic Meter (cyst brood size x # females w/cysts) by Sample Site						
		April 2006 to June 2007				
SITE	MEAN	STD DEV	CV	MIN	MAX	N
1	5,188	7,702	148	28	25,188	10
2	8,692			8,692	8,692	1
3	4,282	4,292	100	34	14,954	11
4	11,205	21,075	188	69	69,450	10
5	6,331			6,331	6,331	1
6	5,459	6,685	122	27	23,871	11
7	4,938	9,291	188	66	27,557	8
8	3,950			3,950	3,950	1
9	5,248	6,463	123	31	20,490	11

Arithmetic Mean	5,533
Standard Dev.	9,873
Median	2,354

APPENDIX 7.1: DESCRIPTIVE STATISTICS FOR CHLOROPHYLL AND WATER TRANSPARENCY

Chlorophyll-a, Phaeophytin, Total Chlorophyll, and Water Transparency by Date

Chlorophyll –A in ug Se/L

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	7.00	3.14	44.82	2.70	11.00	6
May 6, 2006	4.56	2.59	56.76	2.70	8.00	8
May 24, 2006	3.16	2.36	74.65	1.30	8.00	9
June 12, 2006	4.25	2.44	57.32	2.70	8.00	6
June 29, 2006	6.31	1.40	22.14	5.30	8.00	9
July 10, 2006	3.46	1.77	51.28	1.30	5.30	6
July 27, 2006	7.17	5.28	73.73	2.70	16.00	6
August 18, 2006	4.45	2.16	48.44	2.70	8.00	6
August 25, 2006	3.98	1.68	42.08	1.30	5.30	6
September 18, 2006	1.88	1.66	88.56	0.70	4.70	6
October 14, 2006	20.83	8.01	38.45	13.00	32.00	6
November 20, 2006						
December 2, 2006	30.33	4.41	14.55	23.00	35.00	6
January 26, 2007	41.67	4.97	11.92	37.00	51.00	6
March 15, 2007	33.67	4.16	12.37	29.00	37.00	3
May 7, 2007	7.47	6.86	91.91	1.10	15.00	6
May 23, 2007	1.78	0.89	49.70	0.50	2.70	6
June 9, 2007	1.55	0.34	21.88	1.10	2.10	6
Arithmetic Mean	**10.12**					
Standard Dev.	**12.28**					
Median	**5.30**					

APPENDIX 7.2: DESCRIPTIVE STATISTICS FOR CHLOROPHYLL AND WATER TRANSPARENCY

Chlorophyll-a, Phaeophytin, Total Chlorophyll, and Water Transparency by Date

Phaeophytin in ug Se/L

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	13.1	7.1	54.4	6.7	26.0	6
May 6, 2006	9.9	4.2	42.4	5.5	16.0	8
May 24, 2006	4.8	1.9	39.0	1.3	7.7	9
June 12, 2006	5.1	3.8	75.5	1.3	12.0	6
June 29, 2006	5.2	4.5	87.4	1.3	15.0	9
July 10, 2006	6.5	2.6	40.2	3.9	9.6	6
July 27, 2006	3.5	2.7	77.3	0.5	6.7	6
August 18, 2006	5.2	2.3	44.2	2.1	8.5	6
August 25, 2006	1.8	1.4	77.2	0.3	4.3	6
September 18, 2006	1.2	0.7	54.8	0.7	2.3	6
October 14, 2006	4.7	2.3	49.6	2.0	7.7	6
November 20, 2006						
December 2, 2006	6.5	2.1	32.9	4.1	9.6	6
January 26, 2007	4.8	3.0	62.7	1.1	9.3	6
March 15, 2007	4.2	1.5	35.1	2.6	5.5	3
May 7, 2007	2.7	3.2	117.2	0.1	7.7	6
May 23, 2007	1.2	0.8	71.4	0.1	2.6	6
June 9, 2007	1.6	0.6	35.1	0.9	2.5	6
Arithmetic Mean	**4.92**					
Standard Dev.	**4.20**					
Median	**4.30**					

APPENDIX 7.3: DESCRIPTIVE STATISTICS FOR CHLOROPHYLL AND WATER TRANSPARENCY

Chlorophyll-a, Phaeophytin, Combined Chl-a & Phaeophytin, and Water Transparency by Date

Combined Chl-a and Phaeophytin Pigments in ug Se/L

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	18.9	9.5	50.1	9.4	37.0	6
May 6, 2006	11.5	2.8	24.2	8.0	16.0	8
May 24, 2006	7.7	2.3	30.7	5.6	13.0	9
June 12, 2006	9.3	3.2	34.3	5.6	14.7	6
June 29, 2006	10.2	2.6	25.7	7.4	15.0	9
July 10, 2006	9.3	4.4	46.6	5.6	14.9	6
July 27, 2006	10.6	3.5	32.8	7.4	16.8	6
August 18, 2006	8.2	2.6	31.3	4.8	11.2	6
August 25, 2006	5.8	1.7	29.9	2.7	7.3	6
September 18, 2006	2.6	1.4	55.6	1.4	5.4	6
October 14, 2006	25.6	7.3	28.6	18.1	35.2	6
November 20, 2006						
December 2, 2006	36.9	6.3	17.1	27.3	44.6	6
January 26, 2007	46.5	4.2	9.0	41.1	53.5	6
March 15, 2007	37.9	3.8	9.9	33.6	40.5	3
May 7, 2007	10.2	9.8	96.3	1.2	22.7	6
May 23, 2007	2.9	1.4	46.6	1.8	5.3	6
June 9, 2007	3.1	0.6	18.9	2.3	4.1	6
Arithmetic Mean	**14.07**					
Standard Dev.	**12.98**					
Median	**9.30**					

APPENDIX 7.4: DESCRIPTIVE STATISTICS FOR CHLOROPHYLL AND WATER TRANSPARENCY

Chlorophyll-a, Phaeophytin, Total Chlorophyll, and Water Transparency by Date

Water Transparency (Secchi Disk in cm)

DATE	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	112.5	29.4	26.1	60.0	139.0	6
May 6, 2006	156.7	34.3	21.9	85.0	195.0	8
May 24, 2006	365.2	239.9	65.7	30.0	630.0	9
June 12, 2006	282.6	112.9	40.0	100.0	390.0	6
June 29, 2006	324.5	74.7	23.0	245.0	420.0	9
July 10, 2006	230.5	178.0	77.2	87.0	480.0	6
July 27, 2006	140.0	42.5	30.4	75.0	190.0	6
August 18, 2006	166.7	36.7	22.0	125.0	230.0	6
August 25, 2006	153.6	28.4	18.5	115.0	185.0	6
September 18, 2006	260.0	152.5	58.7	90.0	460.0	6
October 14, 2006	65.5	21.1	32.2	45.0	100.0	6
November 20, 2006	56.2	4.5	8.0	50.0	60.0	6
December 2, 2006	56.0	9.6	17.2	40.0	65.0	6
January 26, 2007	46.7	5.9	12.7	40.0	55.0	6
March 15, 2007						
May 7, 2007	119.8	105.4	88.0	48.0	305.0	6
May 23, 2007	442.3	119.9	27.1	332.0	570.0	6
June 9, 2007	325.0	142.9	44.0	160.0	410.0	6
Arithmetic Mean	**179.3**					
Standard Dev.	**142.2**					
Median	**137.0**					

APPENDIX 8.1: DESCRIPTIVE STATISTICS FOR SELENIUM CONCENTRATION IN *ARTEMIA* BIOMASS, SESTON, AND WATER.

Selenium Concentration in *Artemia* Biomass: Adult *Artemia* (ug Se/g).

DATE	GEOMETRIC MEAN	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006	2.11	2.19	0.64	29.1	1.60	3.30	7.00
May 4, 2006	1.10	1.18	0.46	39.0	0.61	1.90	8.00
May 12, 2006	0.46	0.50	0.21	40.9	0.20	0.72	6.00
May 24, 2006	1.40	1.56	0.77	49.4	0.70	2.90	9.00
June 22, 2006	0.90	0.98	0.41	41.6	0.42	1.60	9.00
July 10, 2006	0.87	1.03	0.68	66.1	0.39	2.30	6.00
July 27, 2006	0.80	0.97	0.61	62.9	0.28	1.80	6.00
August 23, 2006	0.72	0.83	0.42	51.1	0.27	1.40	6.00
August 28, 2006	0.71	0.76	0.26	34.0	0.35	1.10	6.00
September 24, 2006	1.34	1.41	0.51	36.0	0.86	2.00	5.00
October 14, 2006	0.56	0.76	0.47	62.3	0.10	1.20	6.00
November 20, 2006	1.01	1.35	1.16	85.5	0.22	3.60	6.00
December 2, 2006	1.80	1.87	0.50	27.0	1.10	2.40	6.00
January 27, 2007							
March 15, 2007							
May 4, 2007	3.72	3.79	0.76	21.1	2.90	4.75	6.00
May 8, 2007	4.87	4.92	0.81	16.4	3.81	6.01	12.00
May 23, 2007	4.09	4.16	0.89	21.4	3.30	5.63	6.00
June 9, 2007	5.11	5.21	1.13	21.7	3.82	7.07	6.00
June 27, 2007	3.36	3.37	0.20	5.9	3.09	3.61	6.00
July 27, 2007	4.81	4.90	1.05	21.4	3.49	6.00	4.00
August 21, 2007	3.73	3.76	0.59	15.8	3.18	4.60	6.00
August 31, 2007	4.68	4.68	0.25	5.3	4.49	4.99	10.00
2006 Results	**1.06**	**1.20**	**0.72**				
2007 Results	**4.30**	**4.32**	**0.95**				

APPENDIX 8.2: DESCRIPTIVE STATISTICS FOR SELENIUM CONCENTRATION IN *ARTEMIA* BIOMASS, SESTON, AND WATER Selenium Concentration in *Artemia* Biomass: Juvenile *Artemia* (ug Se/g)

DATE	GEOMETRIC MEAN	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006							
May 4, 2006							
May 12, 2006							
May 24, 2006							
June 22, 2006							
July 10, 2006							
July 27, 2006							
August 23, 2006							
August 28, 2006							
September 24, 2006	0.08	0.09	0.04	47.3	0.03	0.15	6
October 14, 2006	0.05	0.06	0.04	74.0	0.02	0.12	6
November 20, 2006							
December 2, 2006	0.51	0.61	0.42	69.2	0.26	1.40	6
January 27, 2007							
March 15, 2007							
May 4, 2007	5.68	5.76	1.00	17.5	4.71	7.41	6
May 8, 2007	10.29	10.52	2.53	24.1	8.25	15.00	12
May 23, 2007	6.93	7.44	2.89	38.8	3.49	11.20	6
June 9, 2007	13.26	15.08	8.52	56.5	7.37	25.64	6
June 27, 2007	4.09	4.18	0.72	22.0	3.16	5.53	6
July 27, 2007	2.65	3.08	2.17	70.5	1.81	5.59	4
August 21, 2007	2.78	2.89	0.88	30.5	1.89	3.96	6
August 31, 2007							
2006 Results	**0.26**	**0.25**	**0.17**				
2007 Results	**6.53**	**6.99**	**2.67**				

***Juvenile values were extremely variable and unreliable. The variability was attributable to the small sample size. Laboratory calculations for selenium on a dry weight basis was prone to error due to the minute final dry weight of the samples. The juvenile age-class is the least represented in terms of biomass among all age-classes. Juvenile selenium values were therefore not considered valid for management purposes nor as an accurate representation of selenium in brine shrimp.**

APPENDIX 8.3: DESCRIPTIVE STATISTICS FOR SELENIUM CONCENTRATION IN *ARTEMIA* BIOMASS, SESTON, AND WATER.

Selenium Concentration in *Artemia* Biomass: Nauplii Biomass (ug Se/g)

DATE	GEOMETRIC MEAN	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006							
May 4, 2006							
May 12, 2006							
May 24, 2006							
June 22, 2006							
July 10, 2006							
July 27, 2006							
August 23, 2006	0.34	0.35	0.10	27.2	0.22	0.47	6
August 28, 2006	0.21	0.24	0.16	63.9	0.12	0.54	6
September 24, 2006	0.22	0.26	0.17	67.1	0.13	0.57	6
October 14, 2006	0.23	0.29	0.22	77.2	0.11	0.62	6
November 20, 2006							
December 2, 2006	0.97	1.01	0.25	25.3	0.56	1.30	6
January 27, 2007							6
March 15, 2007	1.72	1.77	0.49	27.7	1.20	2.10	3
May 4, 2007	3.27	3.56	1.57	44.0	1.77	5.39	6
May 8, 2007	2.05	2.20	0.48	22.7	1.18	2.49	12
May 23, 2007	2.53	2.55	0.40	15.8	2.05	3.03	6
June 9, 2007	2.05	2.09	0.44	21.0	1.34	2.48	6
June 27, 2007	2.45	2.50	0.52	20.9	1.70	3.20	6
July 27, 2007	2.12	2.18	0.55	25.5	1.48	2.63	4
August 21, 2007	2.65	2.65	0.14	5.4	2.50	2.82	6
August 31, 2007	2.30	2.30	0.18	7.7	2.04	2.47	10
2006 Results	**0.36**	**0.43**	**0.18**				
2007 Results	**2.35**	**2.42**	**0.53**				

APPENDIX 8.4: DESCRIPTIVE STATISTICS FOR SELENIUM CONCENTRATION IN *ARTEMIA* BIOMASS, SESTON, AND WATER

Selenium Concentration in Seston in ug Se/g

DATE	GEO-MEAN	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006							
May 4, 2006							
May 12, 2006							
May 24, 2006	0.89	0.96	0.39	40.3	0.50	1.68	9
June 22, 2006	0.68	0.81	0.63	77.6	0.35	2.32	9
July 10, 2006	0.79	0.92	0.65	70.8	0.41	2.21	6
July 27, 2006	0.77	0.78	0.14	17.6	0.60	1.00	6
August 23, 2006	1.33	1.48	0.74	49.6	0.56	2.78	6
August 28, 2006	2.80	3.16	1.27	40.1	0.82	4.27	6
September 24, 2006	2.95	3.11	1.06	33.9	1.53	4.49	6
October 14, 2006	1.81	1.88	0.58	30.7	1.32	2.68	6
November 20, 2006	0.43	0.44	0.08	18.3	0.29	0.51	6
December 2, 2006	0.72	0.77	0.31	39.9	0.40	1.28	6
January 26, 2007	0.51	0.62	0.37	59.6	0.22	1.09	6
March 15, 2007							
May 4, 2007	0.42	0.57	0.55	97.5	0.19	1.66	6
May 8, 2007							
May 23, 2007	1.22	1.64	1.23	75.0	0.37	3.66	6
June 9, 2007	0.55	0.69	0.12	16.8	0.55	0.83	6
June 27, 2007	0.94	1.01	0.41	40.8	0.50	1.67	6
July 27, 2007	1.38	1.96	0.86	44.0	1.35	2.56	4
August 21, 2007	0.96	1.05	0.46	43.5	0.47	1.61	6
August 31, 2007							
2006 Results	**1.32**	**1.43**	**0.58**				
2007 Results	**0.86**	**1.08**	**0.57**				

APPENDIX 8.5: DESCRIPTIVE STATISTICS FOR SELENIUM CONCENTRATION IN *ARTEMIA* BIOMASS, SESTON, AND WATER

Selenium Concentration in Seston in ug Se/L

DATE	GEO-MEAN	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006							
May 4, 2006							
May 12, 2006							
May 24, 2006	0.09	0.09	0.01	12.0	0.07	0.10	9
June 22, 2006	0.06	0.06	0.02	27.7	0.03	0.08	9
July 10, 2006	0.07	0.07	0.02	25.1	0.05	0.10	6
July 27, 2006	0.09	0.09	0.01	13.2	0.07	0.10	6
August 23, 2006	0.08	0.09	0.05	51.0	0.02	0.13	6
August 28, 2006	0.12	0.12	0.02	14.6	0.09	0.14	6
September 24, 2006	0.11	0.12	0.08	67.2	0.07	0.28	6
October 14, 2006	0.13	0.13	0.01	11.1	0.12	0.16	6
November 20, 2006	0.15	0.15	0.01	7.0	0.14	0.17	6
December 2, 2006	0.16	0.16	0.03	20.3	0.12	0.21	6
January 26, 2007	0.08	0.10	0.05	53.5	0.05	0.16	6
March 15, 2007							
May 4, 2007	0.13	0.13	0.03	25.5	0.10	0.20	6
May 8, 2007							
May 23, 2007	0.07	0.08	0.03	37.5	0.02	0.11	6
June 9, 2007	0.06	0.06	0.01	15.3	0.05	0.08	6
June 27, 2007	0.16	0.17	0.06	33.2	0.06	0.21	6
July 27, 2007	0.10	0.11	0.06	51.8	0.03	0.17	4
August 21, 2007	0.29	0.30	0.07	22.2	0.23	0.42	6
August 31, 2007							
2006 Results	**0.10**	**0.11**	**0.03**				
2007 Results	**0.13**	**0.14**	**0.04**				

APPENDIX 8.6: DESCRIPTIVE STATISTICS FOR SELENIUM CONCENTRATION IN *ARTEMIA* BIOMASS, SESTON, AND WATER

Selenium Concentration in Unfiltered GSL Water in ug Se/L

DATE	GEO-MEAN	MEAN	STD DEV	CV	MIN	MAX	N
April 30, 2006							
May 4, 2006							
May 12, 2006							
May 24, 2006	0.63	0.63	0.11	17.9	0.55	0.86	9
June 22, 2006	0.48	0.48	0.07	15.1	0.41	0.59	9
July 10, 2006	0.43	0.43	0.03	6.0	0.40	0.47	6
July 27, 2006	0.64	0.64	0.05	8.0	0.60	0.73	6
August 23, 2006	0.64	0.65	0.14	21.1	0.49	0.88	6
August 28, 2006	0.72	0.73	0.11	14.7	0.63	0.90	6
September 24, 2006	0.69	0.69	0.05	6.6	0.65	0.77	6
October 14, 2006	0.57	0.57	0.05	9.2	0.48	0.62	6
November 20, 2006	0.62	0.63	0.12	19.4	0.47	0.83	6
December 2, 2006	0.68	0.69	0.08	12.3	0.55	0.79	6
January 26, 2007	0.64	0.64	0.08	11.7	0.57	0.76	6
March 15, 2007							
May 4, 2007	0.59	0.59	0.04	6.9	0.54	0.66	6
May 8, 2007							
May 23, 2007	0.60	0.60	0.02	3.6	0.57	0.62	6
June 9, 2007	0.63	0.63	0.04	6.3	0.59	0.70	6
June 27, 2007	0.68	0.68	0.02	3.4	0.64	0.70	6
July 27, 2007	0.68	0.68	0.02	2.7	0.67	0.70	4
August 21, 2007	0.66	0.66	0.06	9.0	0.57	0.73	6
August 31, 2007							10
2006 Results	**0.61**	**0.60**	**0.11**				
2007 Results	**0.64**	**0.64**	**0.05**				

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